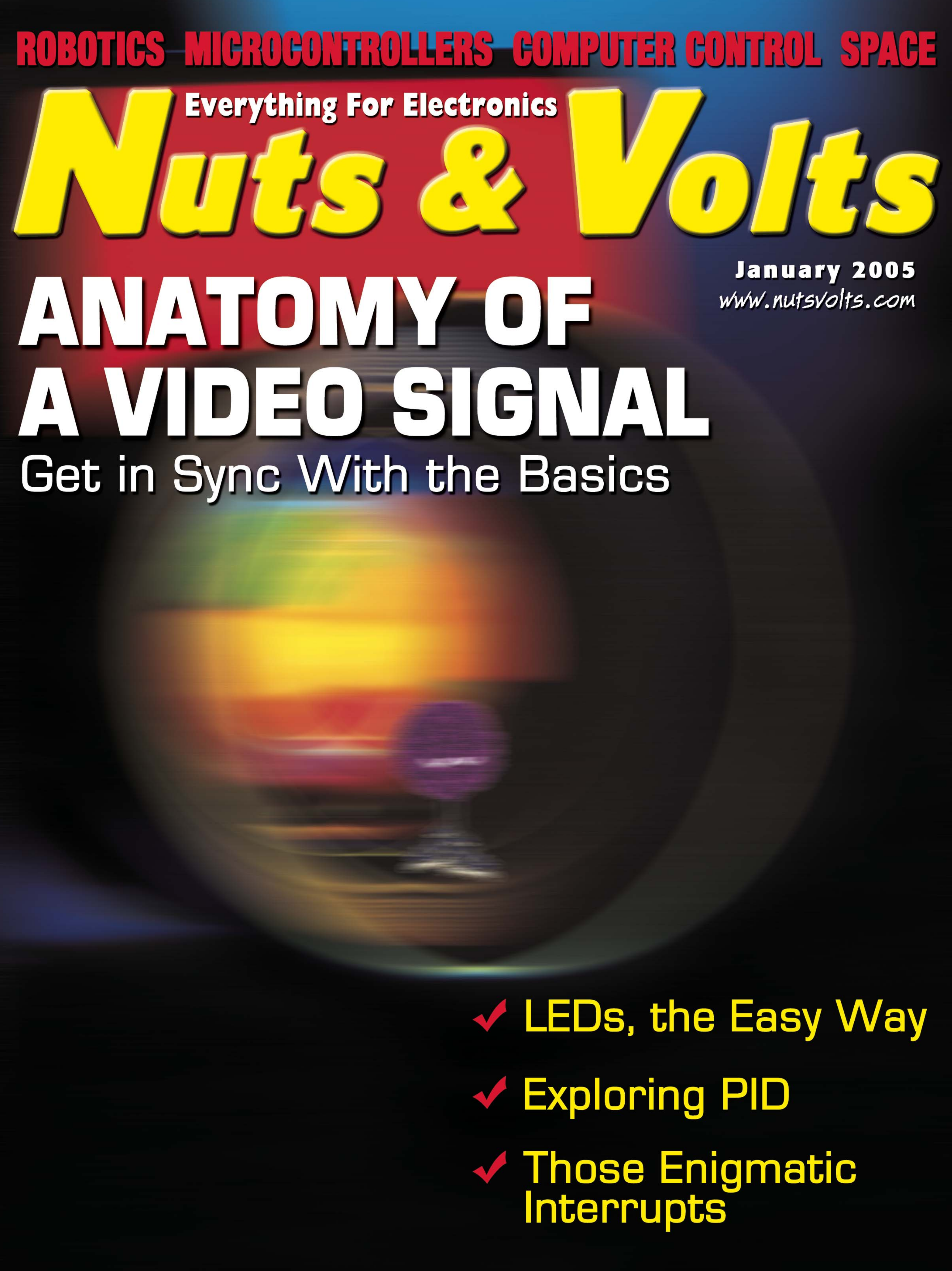
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Nuts & Volts
January 2005
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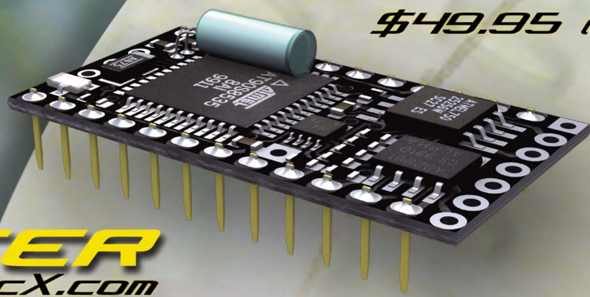

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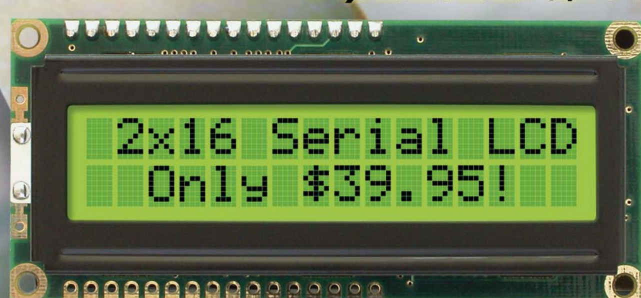

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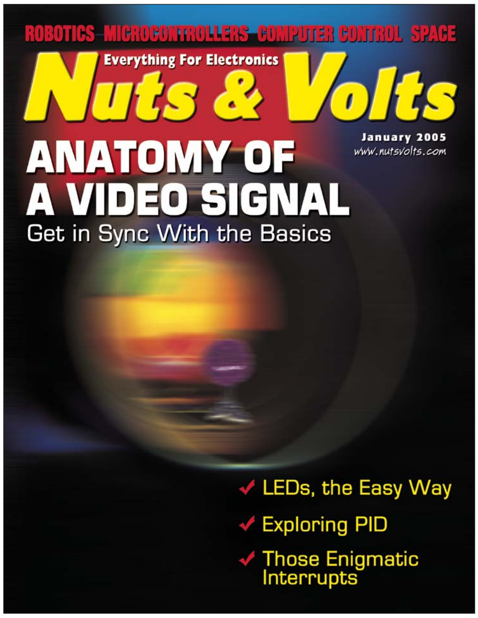

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DEPARTMENTS

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Reader Feedback

Dear Nuts & Volts:

Just a quick request that your magazine publish more articles describing projects for the PIC Microcontroller that DO NOT involve robotics and that DO NOT require STAMP programming. A program in PIC Basic that would involve, say, model railroad block control circuitry or block detection or a Christmas light display would be nice.

Jim Cavanaugh
via Internet

Dear Nuts & Volts:

Your December 2004 column "Open Communication" about ham radio is great. I was interested in just that receiver kit when the issue arrived. It cleared up many of the questions I could not find on the website. I can't wait until the February issue is here for the transmitter kit!

Gene Arnold
via Internet

Dear Nuts & Volts:

Please feature more analog "how-to-circuits" such as op-amps and transistor circuits. I know electronics is constantly changing, but there are still plenty of technicians around who have worked with these types of circuits. There is a real void now that *Radio Electronics* and *Electronics Now* are gone.

Frank Pohs
via Internet

Dear Nuts & Volts:

This is my last year in college (engineering) and your last four magazines were and still are extremely helpful for my senior project class in school. However, I still need some help on building my project (a portable microcontroller-based electrocardiograph recorder).

I'm looking for a way to be able to store the collected data into a USB Flash drive (or USB memory sticks) that can be plugged into the device.

Wilber Hernandez
via Internet

Dear Nuts & Volts:

While catching up on my magazine reading, I came to the nice "Just for Starters" article on counters by Mark Balch in your October 2004 issue. Mark mentioned the problem of spurious clocking due to switch contact bounce.

A few years ago, while working on a project with several push-buttons, I looked for a low parts-count solution and discovered a chip that some of your readers may not know about and may find as useful as I did.

It is the MC14490 hex contact bounce eliminator. It is a CMOS device in a 16-pin DIP. Each of the six circuits takes an input signal from a bouncing contact and generates a clean digital signal four clock periods after the input has stabilized. The clock frequency (bounce delay) of the built-in clock is set by a single external capacitor. You can get this device from Digi-Key for $5.12 each, or $4.10 each if you want 25 of them (**www.digikey.com**).

Bob E. Baker
via Internet

by J. Shuman

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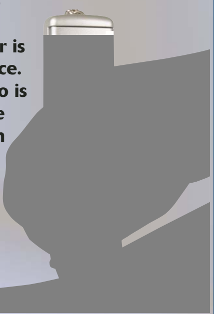


The digital map distance calculator is truly a great device. All you have to do is program the scale of your map, then roll the wheel tip along the intended route. It will then display the ACTUAL REAL WORLD DISTANCE in miles (or kilometres) on the LCD. It is light and compact at around 5-inches long.

Get the Video Quality You Paid For With Our Doctor Video Kit

KC-5390 $64.95

Did you know that you are not getting the best picture from that expensive movie collection you paid good money for? Copy protection is put in place on videos and DVDs for a good reason, but this robs you of the true high quality reproduction that it is capable of. Get the quality you paid for and strip out these annoying signals! It supports composite and S-video signals and can be configured for NTSC or PAL format. Kit includes case, circuit board, all electronic components, and clear English instructions. Note: Some SMD soldering required.

Caution: During signal conditioning, this unit removes copyright protection. Piracy is a crime, & Jaycar Electronics takes no responsibility for its potential for unlawful use.

Remote Control Extender Kit MkII

KC-5209 $13.25

If you have a source device such as a DVD player running to a TV in another room, or perhaps a HiFi system with speakers in the other end of your house, you probably get tired of walking to the other room just to change tracks or fast forward etc. This project effectively transfers the IR signal from your remote control and re-transmits it in the other room! Kit includes case, circuit board, all electronic components, and clear English instructions.

Theremin Synthesiser Kit

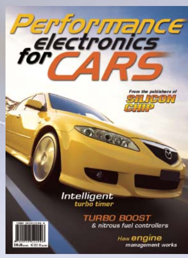
KC-5295
$34.95

The Theremin is a weird musical instrument that was invented early last century but is still used today. The Beach Boys' classic hit "Good Vibrations" featured a Theremin. Kit includes a machined, silk-screened, and pre-drilled case, circuit board, all electronic components, and clear English instructions.

This product is now available pre-built and fully tested - Cat. AM-4025 $64.95

Performance Electronics for Cars Book

BS-5080 $13.60



Australia's leading electronics magazine, Silicon Chip Magazine, has developed a range of projects for performance cars. There are 16 projects in total, ranging from devices for remapping fuel curves, to nitrous controllers, and more! The book includes all instructions, components lists, colour pictures, and circuit layouts. There are also chapters on engine management, advanced systems, DIY modifications, and more. Over 150 pages!
All of the projects described are available in kit form, exclusively from Jaycar.
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KC-5369 $49.95

If you want a great value frequency meter, then this project is for you. It features Autoranging operation for ease of use, switching between its three ranges. High resolution of 0.1Hz up to 150Hz, 1Hz between 150Hz and 16MHz, and 10Hz above 16MHz. It can be powered by a 9V battery or wall adaptor (not included) and the case measures just 5 1/8" x 2 5/8" x 1". Kit includes case, circuit board, electronic components, and clear English instructions.

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Circle #82 on the Reader Service Card.

Micro Memories

The Yamaha CX5M: The Music Computer — '80s Style

These days, recording music on a PC is a surprisingly straightforward affair. Once you master a program like Cakewalk's Sonar or Steinberg's Cubase, it's a matter of if you can dream it up, you can record it. With programs like Sony's Acid, you don't even need to be much of a musician: just layer various loops to taste and you can start making music.

Back in the 1980s, it was a different story. Back then, we had to walk barefoot in the snow for miles — uphill both ways — to get to our local music store and use stone knives and bearskins to record our music. And we liked it just fine, dagnabit!

Well, no we didn't because, actually, we had to use the first generation of mass produced computer music technology and it was pretty brutal.

Meet the CX5M

A case in point was the Yamaha CX5M, sold as a complete, modular music system. It essentially put the guts of a Yamaha DX21 synthesizer inside of a CPU with a QWERTY keyboard and MIDI interface. To control it, the keyboard/CPU had a multi-pin connection designed to accept a 66-key music keyboard (the kind with black and white keys, not ones that say QWERTY on them — that was Yamaha model number YK10, incidentally). It wasn't touch sensitive and it lacked a pitch-bending wheel, but it had a decent feel to it.

The computer used a Z80 chip as its microprocessor and MSX as its operating system (**www.faq.msxnet.org**), which was popular in the early '80s in Europe, Asia, and South Korea, but made few inroads into the US.

The DX21 synthesizer inside of the CX5M was the baby brother to Yamaha's enormously popular (and more expensive) DX7 (there'll be a test later on all of Yamaha's model designations), which popularized a new form of synthesis: digital frequency modulation — FM, for short. Its pure, bell-like tones were seemingly used on every hit record made in the 1980s and used examples of DX7s can be found in music stores to this day.

The CX5M didn't have a dedicated monitor; instead, an adaptor cable with an RF output was designed to be used with a standard TV, much like the original Atari 2600 and other early video games. I ended up using an old 14" turret dial TV for my CX5M. But that's okay, the graphics in the CX5M were no great shakes — we're not talking Apple Macintosh here.

The CX5M's CPU accepted data two ways: it had an Atari-like cartridge interface and Yamaha produced a variety of cartridges for the machine (more on those in a moment). Like older, 1970s era computers, you could plug a cassette recorder into it. Originally, this was used simply to save programs and files created by the user, but a year or two into the (short) lifespan of the CX5M, Yamaha released a couple of tapes to reprogram the CX5M's synthesizer with new sounds. One tape was mostly musical instruments; the other was mostly sound effects.

How Did It Sound?

Curiously for a unit marketed by Yamaha (at least in the US) towards musicians and heavily advertised for a year or two in music trade magazines, the unit didn't boot directly to the synthesizer. Instead, when first turned on, it defaulted to a DOS prompt and the user had to type "Call Music" to get into the synthesizer. Great engineering, fellas!

The CX5M.

MIDI and keyboard outputs.

Once it was activated, though, how did the synthesizer sound? Pretty good, actually — it was capable of very high quality sounds. (They were very clear and bright, though. I found that I needed to warm many of them up by running them through chorus effects, phasers, and flangers to get sounds that “sat” in recordings better.)

Like its big brother — the DX7 — the CX5M was especially good at mimicking tones that already had a bell-like quality to them: there were great electric piano, tubular bell, xylophone, and glockenspiel sounds.

Programming Nightmare

The problem was that it was a bear to program these sounds — both programming new sounds and programming compositions based on those sounds. One of the first cartridges that Yamaha introduced for the CX5M was the YRM-101 FM Music Composer software, which allowed for writing scores on a staff-like interface on the screen.

As I recall, it didn’t allow for much — if any — recording of real time playing, so everything had to be entered via the keyboard — a daunting task.

MIDI was a relatively new concept when the CX5M debuted, having only been developed by Roland, Oberheim, Sequential Circuits, and other musical electronics manufacturers beginning in 1981. However, it was well established enough by 1985 that the CX5M came equipped with MIDI in and out jacks. I recall mating the unit to my Roland TR-707 drum machine and using the CX5M to sync up drums with compositions I wrote using the Music Composer cartridge and recording both the CX5M and the drum machine simultaneously to my four-track cassette recorder (not exactly Vangelis or Peter Gabriel territory, but you have to start somewhere and, remember, this was pretty much the state of home music recording in 1986).

Another early cartridge for the CX5M was catalog number YRM-103, their DX7 voicing program. It was designed to simplify the programming of Yamaha’s then-flagship DX7 synthesizer — a daunting task for even the most experienced electronic musician.

Eventually — and I’ll bet I wasn’t alone — I simply ended up using the computer’s synthesizer almost exclusively and playing it in real time on recordings. Like I said, you couldn’t program it — but it sure sounded pretty good when you played it.

Also, just as with the DX7, reprogramming the synthesizer in the CX5M for new sounds was extremely difficult and I suspect that — just as with the DX7 — most musicians

The YK10 keyboard.

The accompanying voice cassettes.

relied primarily on the CX5M's presets (a list of which is available — but in German — at **www.online.no/~eiriklie/CX5MFAQ.html**) and additional sounds, such as those in their voice data cassettes.

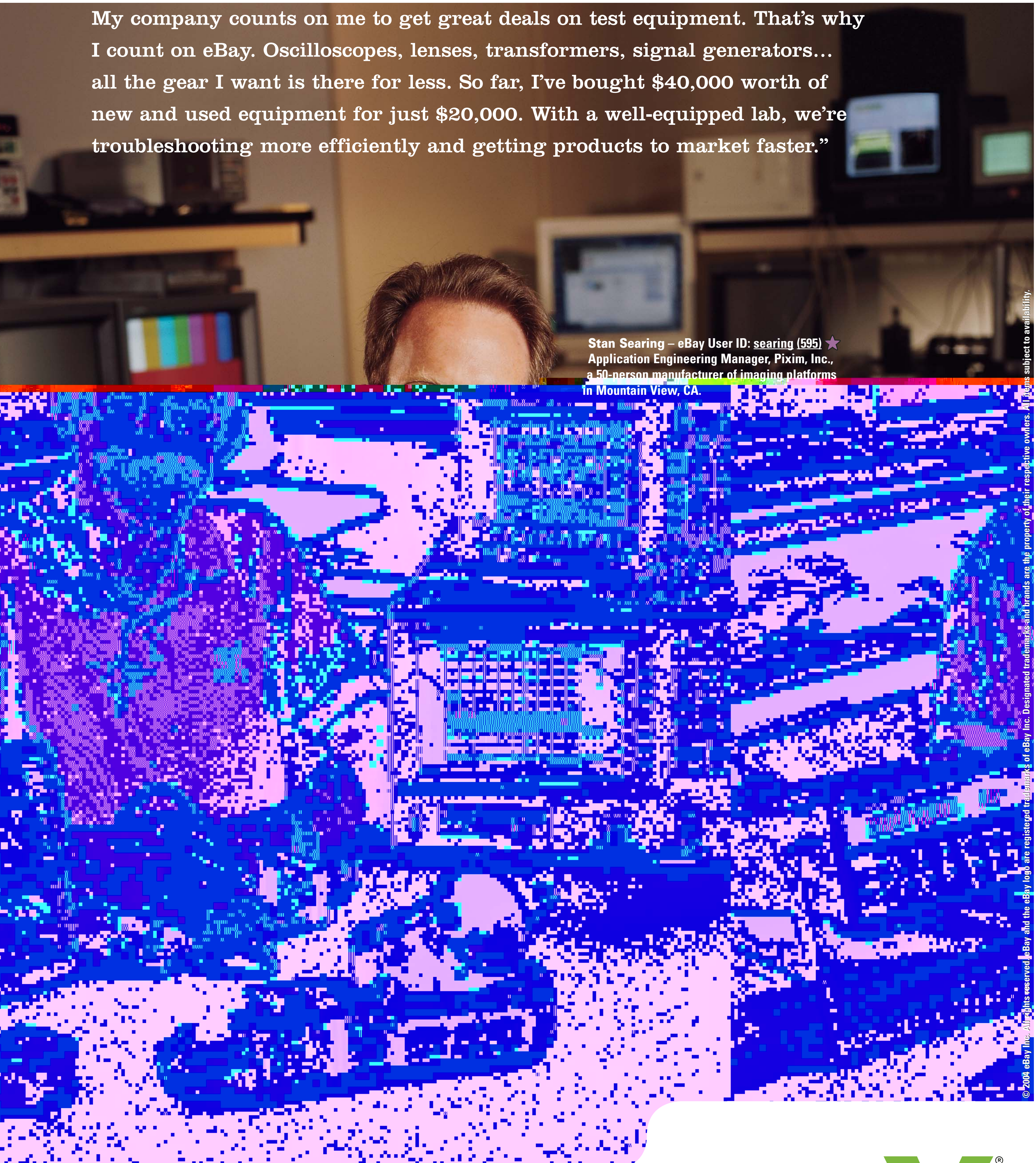
Stepping Stone to the Future

Even up to the 1970s, the synthesizers of the past were bulky machines with seemingly hundreds of cables dangling from telephone switchboard-like interfaces. The first all-synthesizer score in Hollywood — for the 1956 sci-fi classic *Forbidden Planet* by the husband and wife musician team of Louis and Bebe Barron — took three months to complete and utilized equipment that filled their Manhattan, NY apartment.

Today, an average personal computer — even a laptop — can record music, duplicate all of the great synthesizers of the past, and allow its users to create new sounds, as well.

It took a long time, though, to get to this point and the Yamaha CX5M — even if it was difficult to program — put some great sounds in the hands of its users. **NV**

"Lower costs, higher output—it's easy to measure the value of eBay.



My company counts on me to get great deals on test equipment. That's why I count on eBay. Oscilloscopes, lenses, transformers, signal generators… all the gear I want is there for less. So far, I've bought $40,000 worth of new and used equipment for just $20,000. With a well-equipped lab, we're troubleshooting more efficiently and getting products to market faster."

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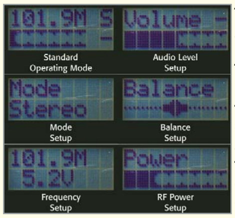
- ✔ 25mW and 1W models!

For nearly a decade we've been the leader in hobbyist FM radio transmitters. Now for 2005 we introduce our brand new FM30 series of FM Stereo Transmitters! We told our engineers we wanted a new technology transmitter that would provide FM100 series quality without the advanced mixer features. They took it as a challenge and designed not one, but TWO transmitters!



The FM30 is designed using through-hole technology and components and is available only as a do-it-yourself kit, with a 25mW output very similar to our FM25 series. Then the engineers redesigned their brand-new design using surface mount technology (SMT) for a very special factory assembled and tested FM35WT version, with 1W output for our export market! Both are designed around an RF tight vinyl clad metal enclosure for noise free and interference free operation. All settings are done through the front panel digital control and LCD display! All settings are stored in the non-volatile memory for future use.

Both the FM30 and FM35WT operate on 13.8 to 16VDC and include a 15VDC plug in power supply. The stylish metal case measures 5.55"W x 6.45"D x 1.5"H and is available in either white or black. *(Note: The end user is responsible for complying with all FCC rules & regulations within the US, or any regulations of their respective governing body).*

FM30	**Digital FM Stereo Transmitter Kit, 0-25mW White**	**$199.95**
FM30B	**Digital FM Stereo Transmitter Kit, 0-25mW, Black**	**$199.95**
FM35WT	**Digital FM Stereo Transmitter, Assembled, 1W, White**	**$299.95**
FM35BWT	**Digital FM Stereo Transmitter, Assembled, 1W, Black**	**$299.95**

Professional FM Stereo Radio Station

- ✔ Rock stable PLL synthesized
- ✔ Front panel digital control and display of all parameters!
- ✔ Professional metal case
- ✔ Super audio quality!
- ✔ 25mW and 1W models!

Our FM100B is the updated version of a truly professional frequency synthesized radio transmitter station in one durable, handsome cabinet. It is used all over the world by serious hobbyists as well as churches, drive-in theaters, and schools. No one else offers all of these features at this price! The included frequency display and audio level meters assist in easy operation. The "B" version now includes some additional functionality including a line level monitor output, improved stereo separation, spectral purity, audio clarity, and adjustable RF Output. An exclusive selectable microphone mixer and auto AGC circuit combines your local mic audio with your music input or mutes the music when mic audio is present. You don't even need an external mixer!

Sound quality is impressive; it rivals commercial stations. Low pass input filtering plus peak limiters put maximum "punch" in your audio, and prevent overmodulation distortion. No wonder everyone finds the FM100B to be the answer to their transmitting needs... you will too! The kit includes a sharp looking metal cabinet, whip antenna, and built-in 110/220 volt AC power supply. An external antenna connection allows hook-up to high performance antennas like our TM100 and FMA200. We also offer a high power export version of the FM100B that's fully assembled with one watt of RF power for miles of program coverage. Many islands and villages use it as their local radio station! The export version can only be shipped outside the USA, or within the US if accompanied by a signed statement that the unit will be exported. *(Note: The end user is responsible for complying with all FCC rules & regulations within the US, or any regulations of their respective governing body).*

FM100B	**Super-Pro FM Stereo Radio Station Kit, 5uW-25mW**	**$269.95**
FM100BEX	**High Power Version, 5uW-1Watt Output**	**$349.95**
FM100BWT	**High Power Version, 5uW-1Watt, Factory Assembled**	**$429.95**

Professional Synthesized Stereo FM Transmitter

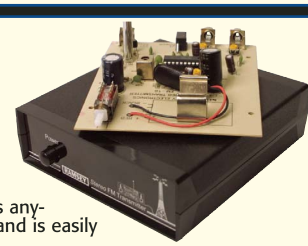
- ✔ Fully synthesized 88-108 MHz for no frequency drift
- ✔ Line level inputs and output
- ✔ All new design, using SMT technology

Need professional quality features but can't justify the cost of a commercial FM exciter? The FM25B is the answer!

A cut above the rest, the FM25B features a PIC microprocessor for easy frequency programming without the need for look-up tables or complicated formulas! The transmit frequency is easily set using DIP switches; no need for tuning coils or "tweaking" to work with today's 'digital' receivers. Frequency drift is a thing of the past with PLL control making your signal rock solid all the time - just like commercial stations. Kit comes complete with case set, whip antenna, 120 VAC power adapter, 1/8" Stereo to RCA patch cable, and easy assembly instructions, and the SMT parts are factory preassembled - you'll be on the air in just an evening!

FM25B	**Professional Synthesized FM Stereo Transmitter Kit**	**$139.95**

Professional Synthesized AM Radio Transmitter



- ✔ Fully frequency synthesized, no frequency drift!
- ✔ Ideal for schools
- ✔ Microprocessor controlled
- ✔ Simple settings

Run your own radio station! The AM25 operates anywhere within the standard AM broadcast band, and is easily set to any clear channel in your area.

It is widely used by schools - standard output is 100 mW, with range up to ¼ mile, but is jumper settable for higher output where regulations allow. Broadcast frequency is easily set with dip-switches and is stable without drifting.

The transmitter accepts line level input from CD players, tape decks, etc. Includes matching case & knob set and AC power supply!

AM25	**Professional Synthesized AM Radio Transmitter Kit**	**$99.95**

Tunable FM Stereo Transmitter

- ✔ Tunable throughout the FM band, 88-108 MHz
- ✔ Settable pre-emphasis 50 or 75 µSec for worldwide operation
- ✔ Line level inputs with RCA connectors

The FM10A has plenty of power and our manual goes into great detail outlining all the aspects of antennas, transmitting range and the FCC rules and regulations. Runs on internal 9V battery, external power from 5 to 15 VDC, or an optional 120 VAC adapter is also available. Includes matching case!

FM10C	**Tunable FM Stereo Transmitter Kit**	**$44.95**
FMAC	**110VAC Power Supply for FM10C**	**$9.95**

Tunable AM Radio Transmitter

- ✔ Tunes the entire 550-1600 KHz AM band
- ✔ 100 mW output, operates on 9-12 VDC
- ✔ Line level input with RCA connector

A great first kit, and a really neat AM transmitter! Tunable throughout the entire AM broadcast band. 100 mW output for great range! One of the most popular kits for schools and scouts! Includes matching case for a finished look! The AM1 has been the leading Scouting project for years and years. Try out your kit skills and at the same time...get on the air!

AM1C	**Tunable AM Radio Transmitter Kit**	**$34.95**
AC125	**110VAC Power Supply for AM1C**	**$9.95**

Tru-Match FM Broadcast Antenna

We've been besieged with calls asking us where to get a good quality FM Broadcast antenna. Remember, matching your antenna to your transmitter is the single most important link in your transmitter setup - and a good antenna and match are the secret to getting maximum range.

- ✔ Fully weatherproof-rugged PVC construction
- ✔ Matches 50 or 75 ohm systems
- ✔ Tunable for a perfect match over the entire 88-108 MHz FM band
- ✔ 25 watt RF power maximum

When we say "match" we mean electrical impedance match... if the proper impedances are not maintained between transmitter and antenna, power is reflected away from the antenna and back into the transmitter! This can cause the final amplifier stage to be damaged, not to mention spurious signals and lousy range. Don't forget, there are three important factors in your broadcast range: antenna, antenna, and antenna! Buy this kit and get the most from your FM Broadcaster!

TM100	**Tru-Match FM Broadcast Antenna Kit**	**$69.95**

What's New For 2005

The Newest Neatest Stuff!

Audio/RF Signal Generator NEW!

✔ DDS and SMT technology!
✔ 0 Hz to 5 MHz at 0.1Hz resolution!
✔ 0 to 10V peak to peak output level
✔ Sine, Square, or Triangle waveform

Following our world famous SG550, we are proud to introduce the SG560, the next generation signal generator!

To begin with we increased the frequency range all the way up to 5MHz and all the way down to 0Hz (yes, we mean zero...or DC!) continuously in 0.1Hz steps across the entire range! Then we gave it a variable output level all the way up to 10V peak to peak in either Sine, Square, or Triangle waveforms! You can also provide a DC offset to the output to recreate TTL, 4000 series logic levels, low voltage logic levels, AC waveforms with a DC component, or just plain AC signals!

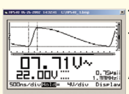
SMT and DDS technology is used throughout the SG560 for ultimate performance and reliability. If you're looking for a lab quality sig gen at a super hobbyist price, the brand new SG560 fits the bill...and a whole lot more!

SG560WT Audio/RF Signal Generator, Factory Assembled $329.95

Hand Held Digital Scope With DVM Readout NEW!

✔ Digital waveform and measurement display!
✔ 10MHz and 40MHz sample rates!
✔ Backlit LCD display
✔ RS232 output (40MHz model only)
✔ Charger, case, probes included

We've seen a lot of portable scopes and scope/meters, and we've also seen the price tags! They have always been way out of the reach and budget of the hobbyist. No more! Now for close to the price of a good DMM you can have a personal scope that also has DVM readout for dBm, dBV, DC, and True RMS! Frequency readout is also displayed on the screen through markers, plus the scopes have two memories for digital storage.



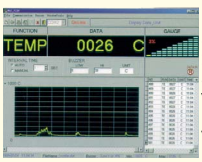
The 40MHz model also includes an RS232 output and serial interface to capture the screen display on your scope to your PC at the mere push of a button! These scopes run on 5 standard AA Alkaline batteries (not included) which provide up to 20 hours of use. You can also use rechargable AA NiMH batteries instead and they'll be charged with the included power supply! Both units come with a custom foam lined high impact carrying case, set of high quality scope probes, AC power adapter and a comprehensive user's manual. If you're working with electronic circuits, automotive applications, audio and stereo applications or other applications, the personal scope is for you...at a price that can't be beat!

HPS10SE	**Personal Handheld 10MHz Digital Scope**	**$229.95**
HPS40	**Personal Handheld 40MHz Digital Scope w/RS232**	**$299.95**

Dual Display DMM With RS232 Output NEW!

✔ RS232 output to your PC!
✔ Digital and analog bargraph display
✔ Backlit LCD display with data hold
✔ Manual and auto ranging
✔ Includes probes, RS232 cable, & software

We gave you an inexpensive pocket DMM for under 20 bucks. Then we gave you a super multi-purpose professional multimeter that measured virtually everything for 40 bucks. What's next, you ask? You won't believe it! Everything PLUS RS232 serial data output for connection to your PC! That's right, now you can measure, control, and store your DMM and its readings on a graphical display on your PC!



Features both auto and manual ranging with a large 3¾ digit display with a 38 segment analog bargraph. Selectable backlight and data display hold features are also included. Plug in the provided DB9 serial cable to your PC, load the included software, and you're off and running with a remote control digital multimeter from your PC! Includes standard test probes, temperature test probes, professional rubber holster, RS232 cable, installed 9V battery, Windows software CD, all in a neat travel case. *(Hard to believe for $85 isn't it!!)*

DVM345DI Dual Display DMM With RS232 Output $84.95

Metal Detector Wand NEW!

✔ **Professional Quality**

Just like at the airports, this hand held metal detector wand detects the smallest metal objects hidden in both people and packages. Rocker switch turns the unit on and power is indicated with a green LED. When metal is detected, a red LED is illuminated along with an alert tone. Headphone jack is provided for private security checks. Runs on a standard 9V battery and includes a case & strap. Factory assembled & tested.

CS10MD Security Wand $54.95

Vehicle EL Wire Set NEW!

✔ **Sound activated electroluminescence!**

Now this is neat stuff! Nearly 10' of electroluminescent wire to install in your car. BUT...it gets better! A built-in sensor modulates the EL wire to the beat of music! Can be set for full mode, music mode, or off. Plugs into 12VDC car jack. Fully assembled.

NWRR30	**Red EL Kit**	**$27.95**
NWRG30	**Green EL Kit**	**$27.95**
NWRB30	**Blue EL Kit**	**$27.95**

Electronic Watch Dog NEW!

✔ **Sound activated barking dog on a PC board!**

It's nice to have a barking dog to react to someone at our door. But not all of us can have a dog! No problem there, build your own! Two distinct barking sounds are sound activated with a built-in microphone that has adjustable sensitivity. I wish my dog had adjustable sensitivity! This dog eats 9-12VDC. Easy kit assembly.

K2655 Watch Dog Kit $32.95

Stereo Super Ear NEW!

✔ **Amplifies sound 50 times!**

The "Super Ear" is an ultra high gain amplifier that includes two super sensitive mics at a 45 degree angle to give you a true stereo output. Includes on/off switch and volume control. Standard audio jack is provided for audio output. Runs on 3 standard AAA batteries (not included). Easy to assemble and fun to use!

MK136 Super Ear Kit $9.95

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Electronics Q&A

In this column, I answer questions about all aspects of electronics, including computer hardware, software, circuits, electronic theory, troubleshooting, and anything else of interest to the hobbyist.

Feel free to participate with your questions, as well as comments and suggestions.

You can reach me at:
TJBYERS@aol.com

What's Up:

Got batteries? I've got answers for monitoring gel-cells. Have a transistor you can't replace? Got that covered, too. And just for fun, I threw in a couple of one-night projects — Geiger meter, anyone?

Operational Amplifier

Q. I recently had to make a circuit to subtract two DC voltages. I first considered using a differential op-amp with one voltage feeding the positive input and the other connected to the negative input. After doing the math to balance out the four resistors for the gain I wanted, it struck me that a summing amp has an advantage: only one feedback resistor has to be changed to alter the gain!

I used an inverting op-amp for one input and fed it to a summing amplifier and ended up with the right number (Figure 1). What are the ramifications between the differential amp and my solution to produce the difference of two voltages?

John
via Internet

A. Operational amplifiers (op-amps) are so named because they were originally used to model the basic mathematical operations of add, subtract, multiply, integrate, etc. in electronic analog computers. Figure 2 shows how the op-amp is configured to "calculate" a few popular math functions.

In the Add circuit, each voltage is weighed equally and there is no limit (well, almost) to the number of inputs you can deal with. Notice that only one resistor (Rf) is needed to define the gain of the circuit and the output is inverted. The Subtract circuit measures the difference between V1 and V2 by using the inverting and non-inverting inputs of the op-amp. It's limited to just two voltages. With the values shown, both of these circuits provide a gain of 10x.

The Weighed and Average circuits are special cases of the Add circuit. The gain of the Weighed circuit is 17.5 for the values shown and the Average circuit has unity gain. In the Inverting configuration, both resistors have to be the same value.

What are the ramifications? Obviously, your inverting design allows you to mix both addition and subtraction with multiple inputs, something a single op-amp can't do. Also, a single resistor determines the gain of the stage. On the other hand, each op-amp in the chain adds its share of noise to the output, which could be a factor in very low voltage measurements.

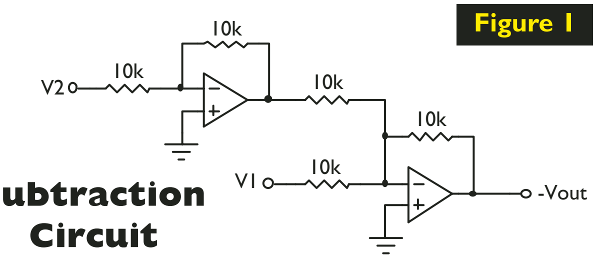


Figure 1
Subtraction Circuit

Ding Dong

Q. I am trying desperately to build a doorbell intercom. I want it to sound like a ding dong or ding ding ding version — something pleasant to that extent. I have close to 100 LM555 timers in my possession and I am willing to use as many as it takes.

Alex Belenkiy
via Internet

A. With the doorbell chime circuit in Figure 3, you'll have close to 98 left over for other projects. Yep, it only takes two 555 chips to make a reasonable facsimile

of a mechanical chime.

The first 555 is a one-shot monostable multivibrator. It controls the second 555 — an astable multivibrator oscillator that drives an 8 Ω speaker. The frequency of the oscillator is, of course, determined by C1, but that would just make a one-tone bell. To change the frequency, the voltage on the control input (pin 5) is modulated by the 2N2222A transistor. When the one-shot output is high, the transistor turns on and grounds the control pin through a 100K resistor. When the output goes low, pin 5 is tied high through the 100K resistor, thus giving the bell its distinctive ding-dong effect.

To further enhance the effect, the astable oscillator is also powered by the output of the monostable multivibrator. When the output is high, voltage is applied to the Vcc and Reset inputs (pins 8 and 4, respectively). When the output goes low, the voltage slowly declines. This causes the volume of the tone to decrease, as it does in a real metal chime. Capacitor C2 determines the time of the decay.

Is My Bot's Battery Dead?

Q. In my new bot, I have two battery power supplies — one 6 volt and one 12 volt. The 6 volt takes care of my servos and the 12 volt is for the drive motor. The batteries are down at the bottom of the bot with the control stuff on top. What I need is a low battery indicator for both banks. I thought to use a green LED for the servos and a red one for the drive batteries. Do you have any answers?

Don
via Internet

A. There are any number of undervoltage ICs that can fill the bill, but I decided on the ICL7665 for this application. It has a proven track record, comes in an eight-pin DIP package, and is readily available. The chip draws a mere 3 µA of power and can operate over a Vcc range of 1.8 to 16 volts, independent of the voltage to be monitored.

The ICL7665 sports two individually programmable voltage detectors; one of the voltage detectors is undervoltage and the other is overvoltage. Both have open drain outputs — which explains the transistor on the Out1 output (Figure 4). It inverts the overvoltage signal into an undervoltage signal by switching on the LED when the overvoltage falls below the

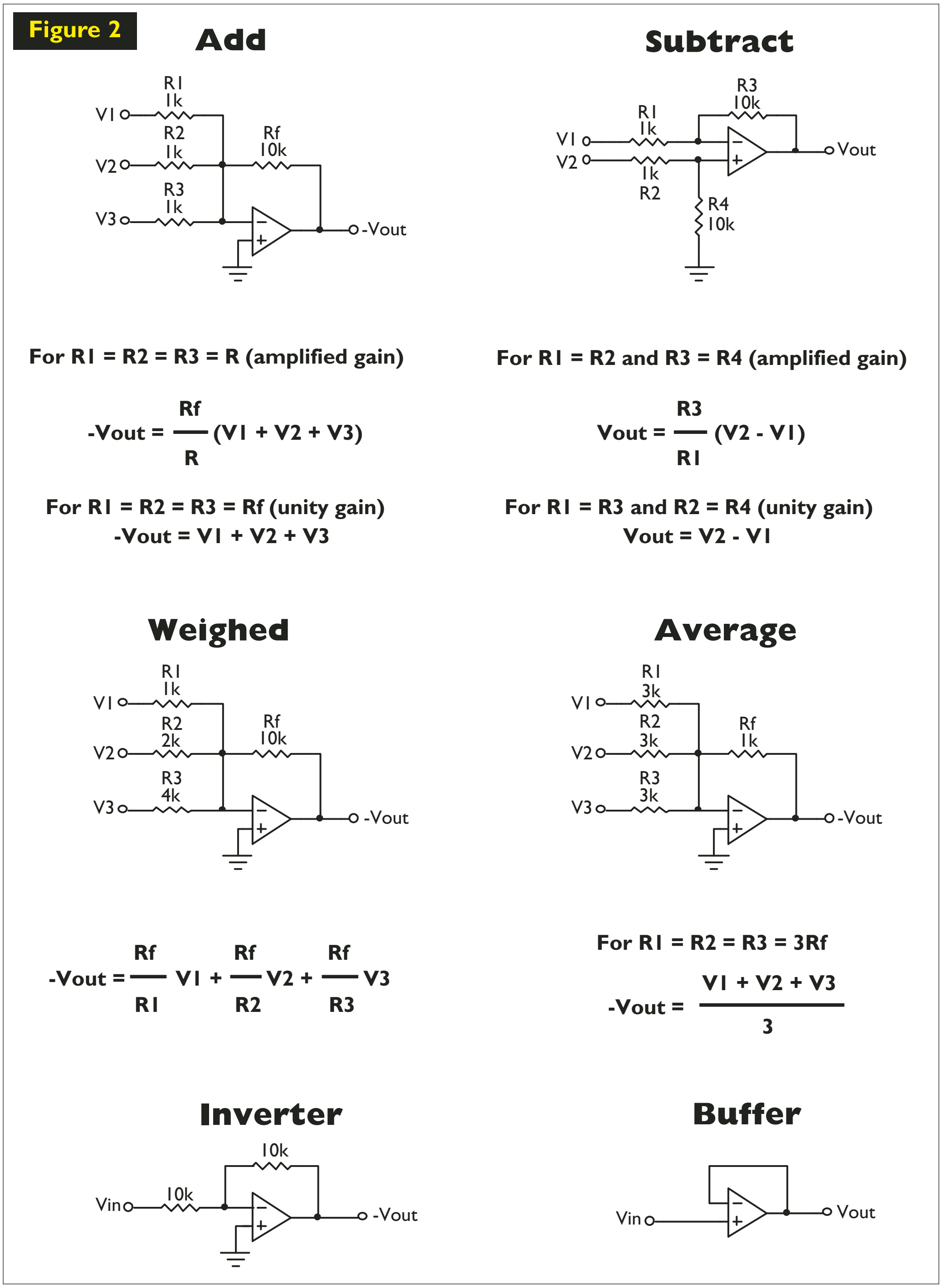
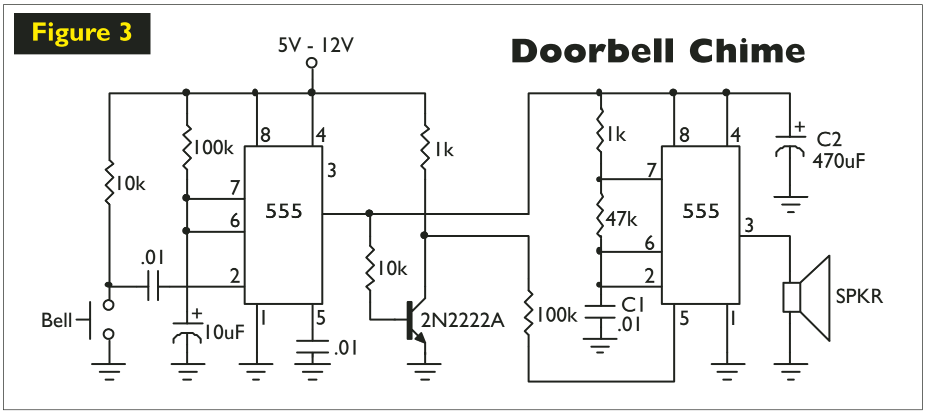


Figure 3



Doorbell Chime

programmed limit. This happens because the 2N2222A transistor's base is shorted to ground and can't conduct when the battery is "overvoltage." When the battery voltage declines below the threshold limit, Out1 goes high (open) and the transistor turns on (clever, huh?).

Both channels have a hysterisis pin that prevents the LEDs from cycling, but I decided not to use them in this design. I feel that a flickering LED will get your attention a lot faster than one that just drones on, especially in the heat of battle.

You'll notice that there are two values for the sense resistors. That's because you didn't tell me whether the batteries were NiCd or gel-cell, so I calculated for both. The LED turns on when there's approximately 20% of the charge left in the battery.

How Dead Is It?

Q. I have recently acquired several 6 V, 9.5 A/H gel-cell batteries. My questions are how do I tell when a gel-cell is dead and how do I build a simple charger for those that are not? Most of the batteries measure between 2 and 4 volts, with some at 0 volts.

Naic
via Internet

A. Unlike NiCd and lithium batteries — which maintain a constant output voltage until "dead" — the state of charge of a gel-cell is very much defined by its voltage. Figure 5 shows the voltage range for a single gel-cell. To find the voltage range for your battery, multiply the voltage by the number of cells in the battery. For a 6 volt, three-cell battery, the range is 5.79 (0%) to 6.39 (100%).

If the voltage of your battery is below the lower limit, don't panic. This happens when the battery is left unattended for long periods. If the battery hasn't been abandoned for too long, you can most likely bring it back to life. What happens when a battery totally discharges is that the plates sulfate.

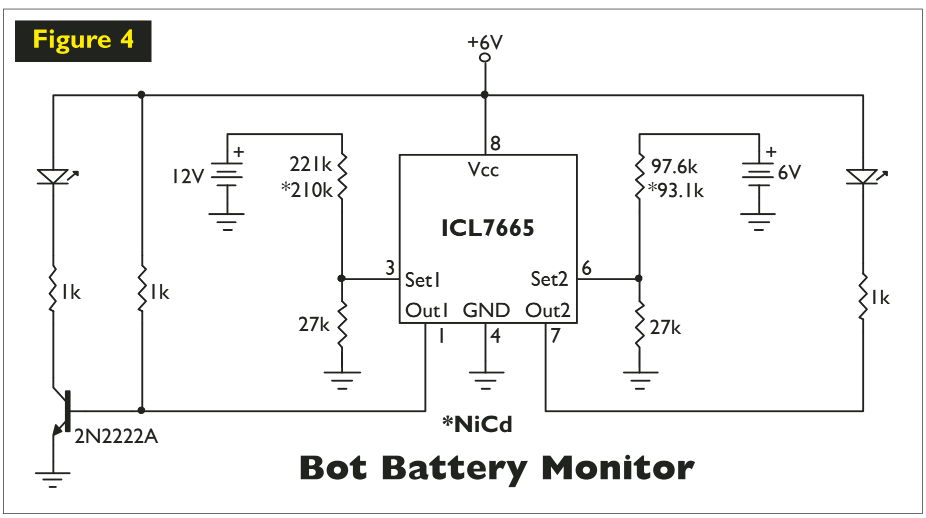
Some say that the ideal way to bring a dead battery back to life is by pulsing it with a high current to "blow" the sulfate off the plates. I suggest a C/1 charge (10 amps, in your case) with a 10% duty cycle.

In this circuit (Figure 6) I'm using the output of the 555 to pulse a TIP145 Darlington pass transistor. The pulse frequency is about 500 Hz, but that's easily adjusted via the 0.22 µF capacitor.

The transformer is 12 volts, center-tapped with an output of 10 amps, like the 7846TR from Marlin P. Jones & Associates (800-652-6733; **www.mpja.com**). The voltage is only partially filtered, hence the 1N4148 diode and 100 µF filter cap so that the Vcc of 555 isn't on the same roller coaster and has a steady power source.

When the charge in the gel-cell reaches 6.2 volts, the pulser turns off and the LED turns on. I know this is short of a full charge, but now it's time to switch the battery over to a conventional charger for final charging.

Figure 4



Bot Battery Monitor

Dip Oscillator Meter

Q. I would like to build a Dip meter in order to learn more about them. Do you have any advice or know of any books that introduce the theory of a dip meter?

James Ko
via Internet

A. Originally known as a grid DIP meter, the dip oscillator is a simple instrument used to measure the resonant frequency of a tuned circuit. Typical applications include antenna matching, filter trap tuning, determining unknown inductance or

capacitance, measuring the length of a coaxial cable, and the list goes on. No physical connection is required. You just have to bring the sense coil in close proximity to the circuit under test.

Basically, the dipper is an LC oscillator that's tuned by a variable capacitor. The sense coil, which is traditionally plugged into a socket at the top of the meter, determines the frequency sweep of the oscillator. When the coil is placed close to a tuned circuit, you adjust the frequency using the variable capacitor. When the frequency of the dip oscillator matches the frequency of the circuit under test, the energy is transferred from the oscillator to the passive circuit. In effect, there is a dip in the output power of the oscillator.

There are many dipper designs implementing every sort of oscillating device from vacuum tubes to transistors to tunnel diodes. The simplest is a one transistor circuit built around an MPF102 FET (Figure 7). It's tuned for a range of 2 to 60 MHz, but small changes in the values of the tuning capacitor and coil can extend that range up or down.

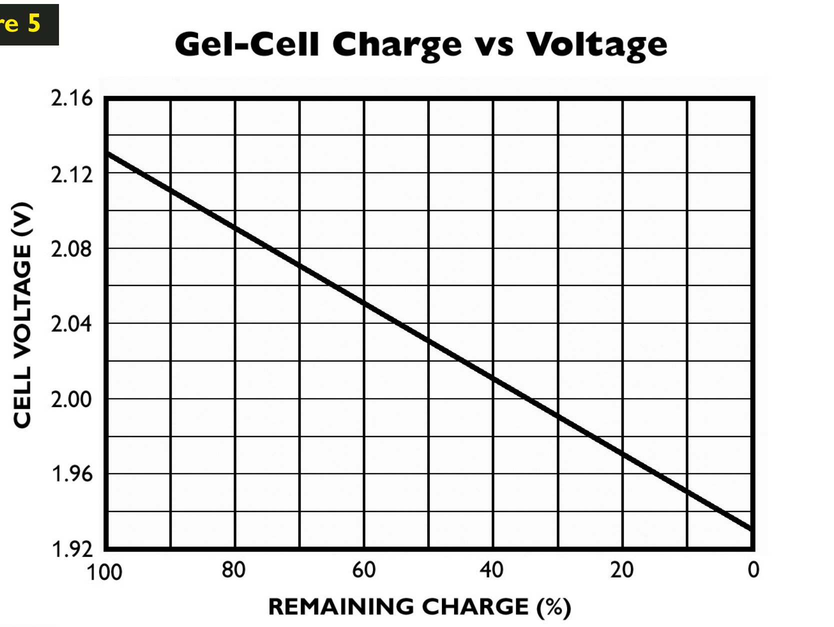
Construction is straightforward, but the connecting wires should be kept short and to the point to avoid spurious radiation.

Calibration is traditionally done by marking the dial using tank circuits of a known frequency. This technique will put you in the ballpark. For those of us who have graduated to the digital age, Figure 8 has a digital counter output.

Coil information is shown in Table 1. PVC water pipe — found at any Home Depot — makes an excellent coil form. The tap is counted from the bottom of the coil and the winding length is critical. Spread the windings apart, if necessary.

Lastly, the wire is enamel coated magnet wire, not plastic insulated.

Figure 5



Obsolete Transistors

Q. Can you please find updated numbers for the following obsolete transistors: HEP724, HEP739, SK3011, SK3003 ... 2N1524, MPS3708, TIS-59? I feel that the TIS-59 can be replaced by a 2N3819 or a MPF-102, but that's only a guess.

Kendrick
via Internet

A. A few years back, there were no less than four major semiconductor makers who offered a line of replacement transistors, including Motorola (HEP), GE (GE-), Sylvania (ECG), and RCA (SK). These parts were originally intended for the replacement, hobbyist, and experimental markets and — in time — found applications in industrial repair and maintenance departments.

Today, only NTE (**www.nteinc.com**) survives. I was able to find all but one of your transistors on their cross reference website (**http://nte01.nteinc.com/nte/NTExRefSemiProd.nsf/$$Search?OpenForm**) — and that's only because the TIS-59 is listed as a TIS59 (originally from TI). Yes, the hyphen matters in the search engine. Once you have

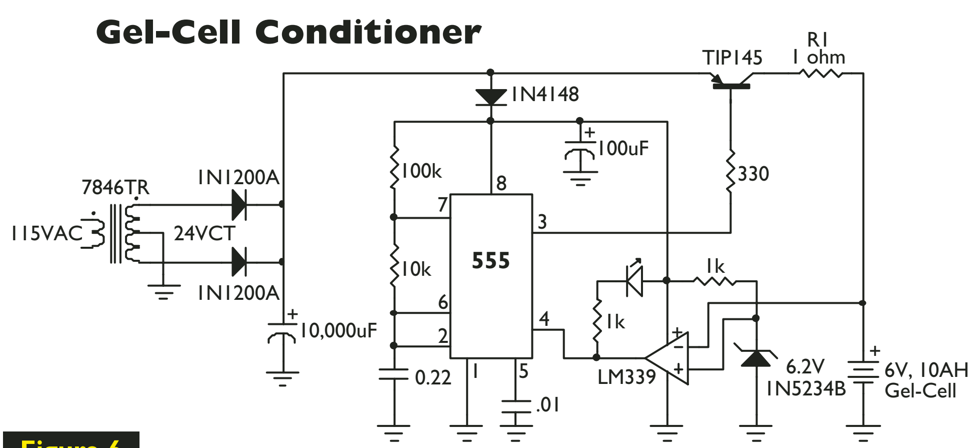


Figure 6

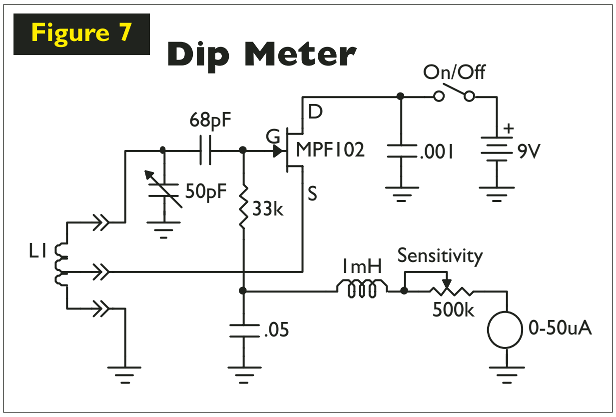


Figure 7

Dip Meter

found an NTE replacement, go to the FindChips website at **www.findchips.com** and enter the NTE number.

Jameco and Mouser both have in-depth stocks of these devices, but they can be more expensive than a generic replacement.

For example, the HEP724 cross references to an NTE123A — which is the equivalent of a 2N2222 that sells for one-third the price.

The NTE website has data sheets that you can use to find a cheaper generic. Follow the guidelines in the question below ("Transistor Selection") to find a suitable replacement from a data sheet. And — yes — the MPF102 is an acceptable substitute for the TIS59, according to their data sheets.

Specialty Transistors

Q. I am an electronics hobbyist and I was wondering if know of any websites that I could visit for semiconductor equivalents. I have been looking for a transistor whose reference is H8N80FI and can't find it in any transistor catalog.

Elimane Bathily
via Internet

A. Not all transistors have a cross reference — especially those which are privately labeled like the H8N80FI. In cases like this, I do a Google search (**www.google.com**). As a rule, I hit nothing, but I got lucky this time and came up with a 2SK1363 — an N-FET power transistor. Unfortunately, this transistor is only available overseas and not stateside, as are many specialty transistors and ICs. Try Donberg Electronics at **www.donberg.ie**

(Before you send that letter, let me say that the 2SK1363 was also used in an Apple CRT monitor and an Apple repair center may still have one or two on a dusty shelf.)

Transistor Selection

Q. My question is what the determining factor is in transistor choice? How interchangeable are the different types? I have a circuit that calls for a 2N3707, which I have never even heard of.

B. Brown
via Internet

A. From an engineering point of view, there are four critical parameters when it comes to choosing transistors: voltage, current, gain, and frequency.

Supposedly, each transistor is custom fit (as in a specific 2N number) to fill a niche for performance and cost. That is, you don't want to pay for performance you don't need, but you do not want to be caught short with a marginal part, either. Hence, all the various numbers.

However, like most electronic devices, a transistor with better specs can always replace one with lesser expectations.

As for the 2N3707 — which is now obsolete — it's an NPN general-purpose audio transistor rated at 30 volts, 200 mA, and a gain of 100 to 400.

To me, that sure sounds like a 2N2222, which is rated at 60 volts, 800 mA, with a gain of 300 at 150 mA. Both are of the same sex — NPN as opposed to PNP — both are silicon (not germanium), and both have an upper frequency limit of 250 MHz. So, why does your design specify the 2N3707? Probably because the designer got a good deal (price break) on this transistor at a time when he needed those parameters.

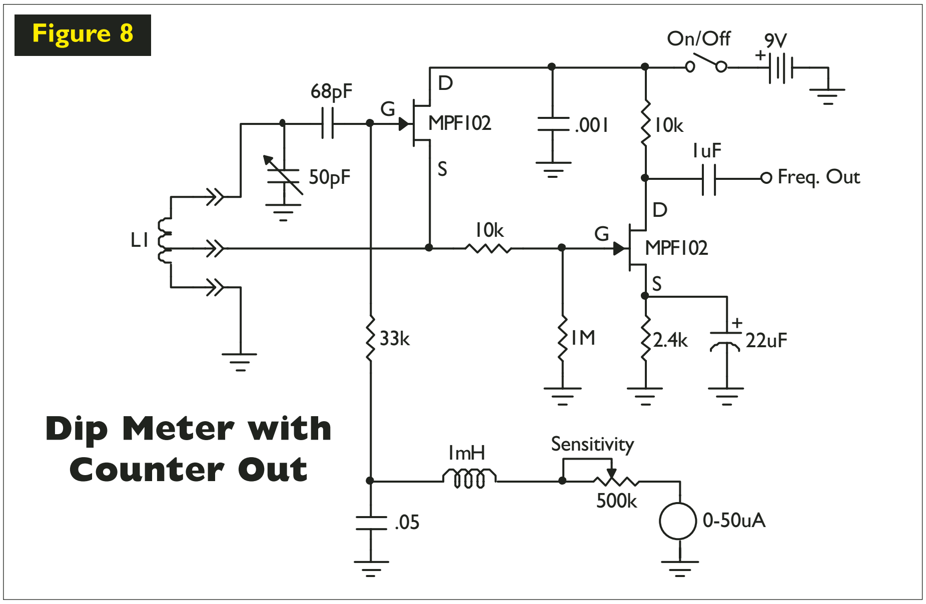


Figure 8

Dip Meter with Counter Out

Radioactive Peanuts

A couple of years ago — January 2003, to be exact — I published a circuit for a Geiger counter using an NE-2 neon lamp. I found the design in an old copy of *Experimente mit Strahlenquellen.*

Many of you had problems with that circuit in that there was too much variation between the NE-2 lamps, making it unusable or impossible to calibrate the counter.

Well, I have done a little research since then and think I have found a better design that uses — of all things — a peanut can. The "Cheap, but Sensitive Radiation Detector" can be found at **www.techlib.com/science/ion.html** The design is by Charles Wenzel, whose designs I trust. Figure 9 shows the basic concept. His commentary is self-explanatory, so I won't go into it here.

The second missing part of the equation was a radiation source. I found that on eBay under the guise of a Coleman lantern mantle. One mantel produces 1.5 mr/hr (about 750 counts per minute) and sells for about $5.00. You can also find them from time to time at K-Mart and camping supply houses. Look for the brand that says "Made in India."

The radioactive ingredient in the mantle is thorium-232. By itself, thorium is only slightly radioactive, emitting only alpha particles that are easily blocked by a thin piece of paper.

However, thorium breaks down into two parts: a small part — the alpha radiation — and a larger part called the decay product. The decay products include radium and radon, which emit alpha and beta particles and gamma rays.

In fact, the longer thorium stands (half-life is 14 billion years), the more radioactive it gets — but that's another story.

Frequency MHz	Number of Turns	Tap at Turn No.	Wire AWG	Coil Diameter	Winding Length
1.8-3.8	82	12	#26	1 1/4	1 9/16
3.6-7.3	29	5	#26	1 1/4	9/16
7.3-14.4	18	3	#22	1	3/4
14.4-32	7	2	#22	1	1/2
29-64	3 1/2	3/4	#18	1	3/4

Table 1. Dip meter coil data.

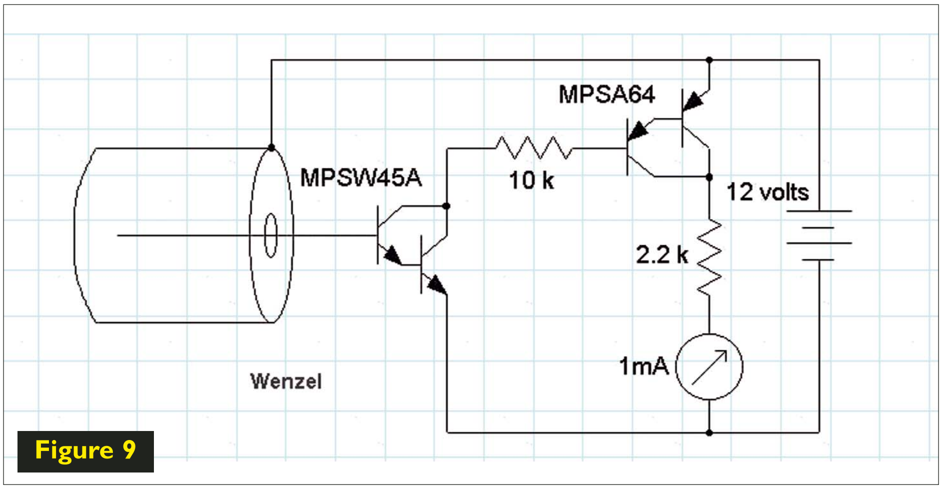


Figure 9

Three Coins in a Fountain

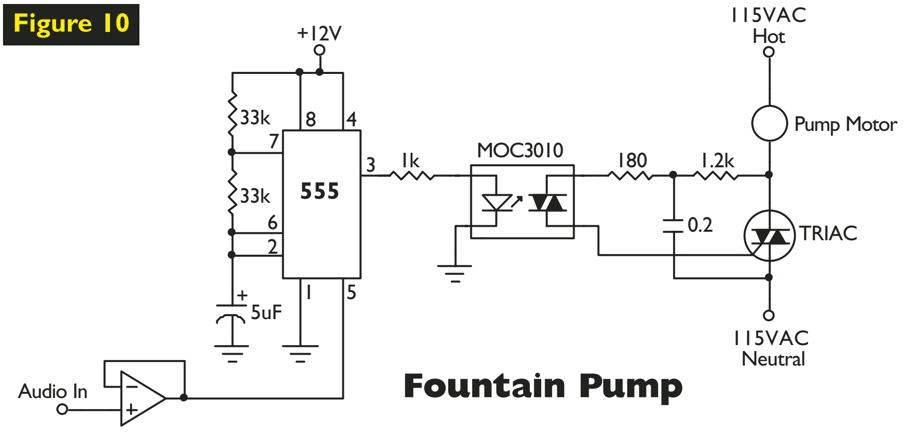
Q. I want to hook up one or more submersible fountain pumps (typically 115 VAC, 0.8 A) to a circuit that will vary the flow of water in concert with the input from a sound source. Should the circuit change the voltage or current?

Bob Slusher
via Internet

A. Controlling the speed of an AC motor is fairly simple. It's done all the time in hand drills, but what you're trying to control is a flow of water, which has a lot of latency — resistance to change in flow. No matter how hard you try, the fountain-head won't follow the fast-moving audio. The controller needs a low frequency filter to turn sporadic into rhythmic. Here's what I'd do (Figure 10).

In this circuit, I've used the control voltage input (pin 5) of a 555 timer to PWM (pulse width modulate) the speed of the motor. With this design, the motor is never completely off — for good reason. Starting a water flow from a stall takes a lot longer than revving it up from a trickle, making your fountain slightly more responsive. It also takes care of the low frequency filter I mentioned earlier by using the inertia of the

Figure 10



Fountain Pump

motor itself.

Like the previous question, you have to provide the audio interface. Just make sure that the voltage sweep on pin 5 is between the Vcc and GND limits or you'll fry the 555 chip.

This input is not linear over this range, which is okay for the type of output you desire. Also, 5 µF may not be ideal for your particular pumps. Play with it until it works right for your display.

MAILBAG

Dear TJ,

In reference to the thermocouple answer (November 2004), back when I was still gainfully employed, we routinely made thermocouples for plant use. The process consisted of twisting the two materials together so that they were in intimate contact and discharging a large capacitor through the junction.

Dave Schoepf
via Internet

Dear TJ,

If you put 12 amps through a 1 Ω resistor, it better be 144 watts instead of 10 W (November 2004 issue)!

Charles D. Geillker
Professor of Physics

Response: *That would be true if the current flowed 24/7, but the thermocouple welder shown in that answer has the current flowing for about 1/10 of a second while the user taps the wires to the carbon rod. This isn't nearly enough time for the resistor to heat up to even 10 watts. It's called duty cycle.* ***— TJ***

Dear TJ,

Your block diagram for a slide viewer will indeed invert negatives, but the color will not be correct. All negative color film uses an orange mask that corrects for impurities in the magenta and cyan dyes. This will make the inverted image appear to have a sickly blue cast.

Bill Runkle
via Internet

Cool Websites!

Learn to speak Aussie.
www.aussieenglishcd.com/multimedia_samples.php

Lots of high voltage stuff.
http://205.243.100.155/frames/lichtenbergs.html

What's up? Kennedy Space Center.
www.ksc.nasa.gov

Circle #55 on the Reader Service Card.

by L. Paul Verhage

Approaching the Final Frontier

Near Space

Adapting Cell Phone Battery Cells for Near Space Use

Due to the extreme cold of near space (NS), hobbyists must be careful when selecting power sources for their NS craft. On one or two occasions, I have lost track of a NS craft, apparently due to cold batteries. To reduce this risk, most of us involved in amateur NS use lithium cells, which can be rated to -60° F.

My source of these cells is S & G Photographics or Fair Radio Sales. These cells come from surplus military battery packs. Each package contains either five or 10 cells that are either D cells or a slightly shortened version thereof. The only risk I face using these surplus cells is that they are 10 years beyond their expiration date. Since the cells are based on a lithium sulfate chemistry, they self-discharge very slowly and still retain most of their original capacity, but — every once in a while — I'll find a bad cell.

If I discover a bad cell before I assemble the battery pack, that's fine. It's the possibility of discovering a bad cell during a mission that has me worried, so I've kept my eye open for an alternative. One alternative is using rechargeable cells that aren't sensitive to cold temperatures. NSTAR's Mark Conner has had success with NiHM cells, for example. However, I hesitate to use NiCds and NiMHs because of their memory effect.

Recently, hobbyists have been able to purchase cell phone batteries through surplus electronics dealers. These batteries use a lithium-ion chemistry, so they're reasonably energy dense (high capacity for their size and weight) and rechargeable. Batteries this good are usually expensive (just wait until you have to replace your cell phone battery), but now that they can be purchased surplus, their cost has become very reasonable.

I purchased several 7.2 V 1,200 mAH batteries from All Electronics for $6.50 each (part number LBAT-35) and the charger for $4.50 (part number BC-9). Being lithium-ion batteries, they don't suffer from the memory effect found in NiCds and they are less susceptible to failure due to cold temperatures. On the negative side, however, is the fact that they are designed for cell phone battery compartments. The battery connector found in a cell phone is not very friendly for use in NS or robotics projects.

In this month's column, I'll describe how you can adapt these inexpensive batteries for your projects. The modification is simple and — when you're done — you'll have a great rechargeable battery to use in your robotic or NS projects.

Figure 1. The cell phone battery in its native state.

Battery Mod

The cells for this battery are sealed in a hard plastic case. Two "springy" metal pins in the cell phone battery case make contact with the metal tabs molded into the battery case. Since I couldn't find a battery holder for cell phone batteries at my local RadioShack, I decided to modify the electrical connection to the battery to suit my needs. Figure 1 shows what the battery looked like before the modification. The cap covering the battery's tabs prevents short circuits when carrying a charged battery in your pocket.

Materials

- Two lengths of 12 gauge, stranded wire (use red and black)
  Note: I used the silicon rubber insulated wire available at R/C car stores
- 2" diameter heat shrink tubing and heat gun
- Two connectors suitable for your projects *Note:* I used a pair of Anderson Power Pole connectors
- Solder and soldering iron
- Wire cutters and strippers
- Electrician's tape
- Masking tape

Procedure

First, a few words of warning. Do not charge your battery before making this modification. Also, watch that you do not accidentally short the battery while modifying it. The modification is safe, but you

need to watch what you are doing.

This modification involves soldering two #12 AWG gauge wires to the battery's tabs and then covering the exposed connection with tape and heat shrink.

So, begin by firing up your soldering iron. After it warms up, apply a thin coat of solder to the entire exposed surface of the electrical contacts of the lithium-ion battery. Do this quickly, as you don't want to heat the metal contacts any longer than necessary. The battery chemistry may not respond favorably to high heat and you certainly do not want to melt the plastic case. I found that the gold-colored contacts soldered very easily.

Cut a red and a black wire to the same length. These wires will become the battery's new power cable, so select the power connectors you plan to use and crimp and/or solder them to one end of each wire. It's easier to terminate your wires now than later, when the battery is hanging from the other end. In my example, I cut my wires 4" long and crimped Anderson Power Poles on the ends.

Strip between 1/8" and 1/4" of insulation from the other ends of the two wires. Bend the ends of the exposed wires at right angles where the insulation ends and tin the exposed ends with solder. Watch out — the wires will stay hot for a while, so be careful when you handle them.

Look at the front of the battery and beneath the tinned electrical contacts. There, you'll see a small positive and a small negative mark imprinted on the plastic battery case. These represent the polarization of the electrical contacts. After determining the polarization of the tinned contacts, solder the wires onto the battery contact. Be sure you solder the red wire to the positive contact and the black wire to the negative contact.

To solder the wires to the battery, I recommend laying a 12 gauge wire on the front of the battery case with its tinned end touching a tinned battery contact. Wrap a strip of masking tape around the battery and wire to hold them together while you solder the wire to the battery contact. When soldering the wire to the contact, quickly apply a well-tinned soldering iron to the wire and battery contact. The solder in the tinned wire and battery contact will melt and fuse together. Remove the soldering iron as soon as the connection is made. Repeat the process on the other wire.

Once the solder has cooled, cut two pieces of electrician's tape and cover the exposed solder joints on the top of the battery. Cut the tape long enough to not only cover the top of the battery, but also to partially cover the sides of the battery. For good measure, wrap a strip of electrician's tape around the top of the battery and cover the ends of the first two strips.

Finish the battery modification by cutting a 2-1/2" length of 2" diameter heat shrink tubing. Slide the tubing over the battery and fully cover both the body of the battery and the ends of the electrician's tape that was used to cover the solder on the battery. Shrink the tubing down.

Figure 2. The modified lithium-ion cell phone battery. Now you can use these great and inexpensive batteries in your hobbies.

When completed, your battery should look like the one in Figure 2. Repeat this modification for the rest of your cell phone batteries.

Charger Mod

Once a battery has been modified, it can no longer charge on its original charger, so let's modify that, too.

Materials

- Small Phillips screwdriver
- 22 gauge stranded wire (in red and black)
- 3/16" heat shrink tubing
- Power connectors to mate to the

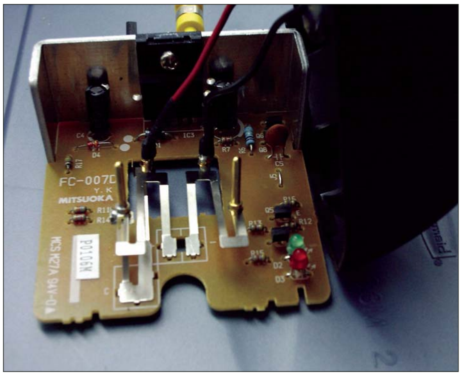


Figure 3. This is what the inside of my charger looks like.

power connectors in the modified battery
- Wire cutters and strippers
- Solder and a soldering iron
- Heatsink clip or other small clamp

Procedure

It shouldn't be necessary to say this, but please make this modification while the charger's wall wart is disconnected from the charger base. Under no circumstances should you make this modification while the charger is plugged into the wall.

Look at the pocket of the charger. You will see two pairs of metal pins. Two metal pins make an electrical connection with the battery and the two other metal pins detect the presence of the battery. Unless a battery is pressed into the charger pocket, the charging pins are not pressed into contact with the charge circuit. In this way, there is no voltage present at the charging pins when the battery is not located in the pocket. It's been a while since I modified my charger, but this is how I made it.

The case of the charger is held together with two Phillips screws located in the bottom of the charger case. Remove these two screws and the case should pop open. The two bottom pins (the battery detecting pins) pull right through the holes in the case. The charging pins also pulled out of the case when I opened it.

Now, look inside the charger and identify the two pairs of leaf springs containing the two battery detecting pins and the two charging pins. The top leaf spring contains the battery detecting pins that protrude from the bottom two holes of the charger pocket. The bottom leaf spring is connected to the two charging pins that protrude from the top two holes of the charger pocket. Notice that the two leaf springs form the switch inside the plastic case that lets current flow into the cell phone battery when it is dropped into the charger pocket.

The first modification to make involves soldering the two leaf springs together so there's always power from the recharge circuit. Use a heatsink clamp and clamp the top and bottom leaves together on the side of the springs where the battery sensing

pins are closed to the leaf contacts (in my charger, this is on the left side of the leaves). Now, solder the leaves together (the leaves appear to be made of brass). After the solder cools, remove the heatsink clamp. The leaves will remain in contact if the soldered connection is good.

The next step is to connect wires and connectors to the charger that can interface with the modified cell phone battery. Cut two lengths of wire (red and black) about 8” long. For my charger, I used #22 AWG stranded wire. We can get by with thinner gauge wire on the charger unit than on the battery because the charger recharges the battery at a low current, whereas the battery may be discharged at a high current.

Crimp and/or solder the same type of connectors used in the battery mod to one end of both wires. Now strip about 1/4” of insulation from the other ends of each wire and tin them. Slide a short length of heat shrink tubing over the wires and push them away from the bare ends of the wires and close to the crimped connectors on the other end (you want to keep the heat shrink away from where you will be soldering). Thoroughly tin the battery charging pins.

If the front of the charger is pointed at you (the front of the charger has the two LED indicators), then the right charging pin is negative and the left charging pin is positive. You can verify this by looking at the charging circuit’s PCB silk screening.

Pass the two #22 AWG gauge wires through the two charging pin holes in the pocket of the charger case. Be sure to pass the black wire through the right hole and the red wire through the left hole. Press one of the tinned ends of wire into contact with a tinned charging pin and heat both of them with a well-tinned soldering iron. Hold the wire in place until the solder cools. Repeat the same thing with the other pin. Once the solder cools, slide the heat shrink over the soldered connection and shrink.

Now, you can close the charger case. Be sure a wire doesn’t get pinched in the case.

I have used my new batteries twice on NS missions and, so far, I’m pleased with the results. **NV**

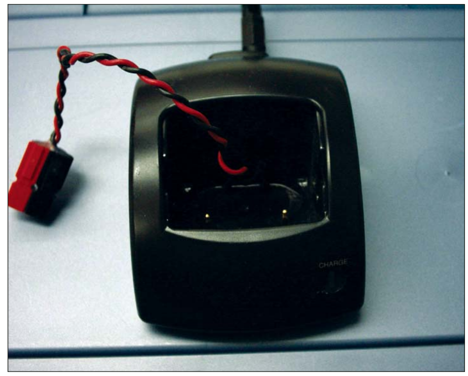


Figure 4. With the case closed, the charger “almost” looks normal.

Go to www.nutsvolts.com — click Electro-Net

by James Antonakos

Electronic Theories and Applications From A to Z

Let's Get Technical

Hop, Skip, and Jump — Pseudo-Random Frequency Hopping

Everyone seems to be jumping onto the wireless networking bandwagon. With more and more devices going wireless, the airwaves are constantly filled with numerous digital "conversations." For ordinary, law abiding wireless users, the congestion is handled using a wireless protocol that allows for reliable communication in a noisy, competitive environment.

However, due to the broadcast nature of wireless networking, other users may try to tap into the wireless network, eavesdropping on the flow of information and looking for useful data.

How, then, can a user enjoy a sense of privacy when using a wireless device? Certainly, we can encrypt the data so that — if intercepted — its meaning remains hidden. For strong encryption, a key with many bits must be used; this, in turn, requires a large set of calculations. Without a fast, dedicated processor, strong encryption may not be feasible for many applications, particularly mobile wireless devices.

One electronic method of providing privacy to a transmitted signal is called Frequency Hopping. In this method, a band of frequencies is broken up into several smaller bands.

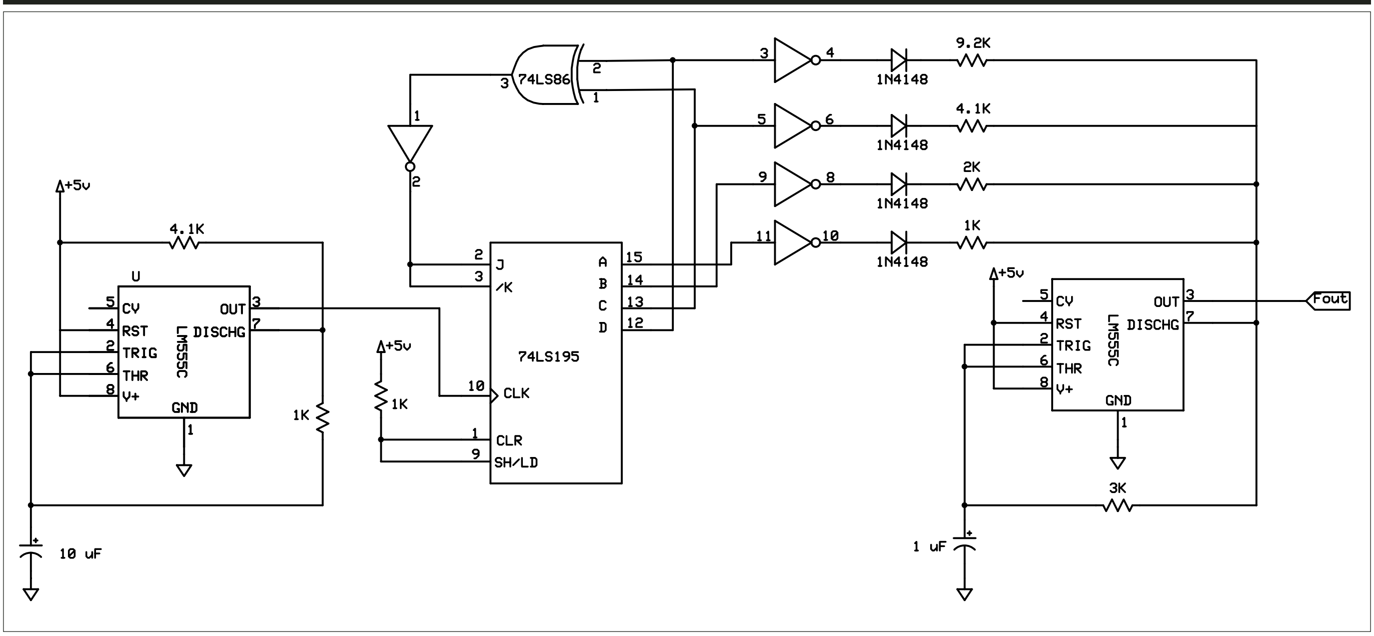
After a portion of information is transmitted at one frequency, the transmitter changes frequencies and continues transmission. When changing frequencies, the transmitter randomly (at least it appears random) selects a new frequency from the set of frequencies in the band.

By choosing a random frequency to jump to for each new transmission, anyone listening in to the transmission must also switch to the new frequency or lose reception of the information.

If enough frequencies are used and the hopping around is composed of a large number of jumps, it will be very difficult for the eavesdropper to receive a valid stream of information.

Figure 1 shows a simple circuit that generates a pseudo-random

Figure 1. Pseudo-random frequency hopping circuit. The first 555 timer clocks the four-bit shift register. The XNOR feedback circuit helps the shift register generate a 15 pattern sequence. Each pattern causes the second 555 timer to oscillate at a different frequency.



sequence of 15 different frequencies, as indicated in Table 1. An Exclusive NOR (XNOR) feedback circuit uses the last two bits of a four-bit shift register to determine the next bit clocked into the shift register. Each new bit clocked into the shift register causes the four-bit output pattern to change.

Note the seemingly random sequence at the DCBA outputs. It is not really random, since the same 15 pattern sequence will repeat over and over. This is because, when the outputs are 0001, the next output will be 0000, which is where we started.

Pattern	Output D C B A	Decimal Value	Frequency (Hz)	Direction of Change
1	0 0 0 0	0	219	N/A
2	1 0 0 0	8	218	Down
3	1 1 0 0	12	215	Down
4	1 1 1 0	14	204	Down
5	0 1 1 1	7	94	Down
6	1 0 1 1	11	142	Up
7	1 1 0 1	13	179	Up
8	0 1 1 0	6	207	Up
9	0 0 1 1	3	162	Down
10	1 0 0 1	9	195	Up
11	0 1 0 0	4	216	Up
12	1 0 1 0	10	210	Down
13	0 1 0 1	5	187	Down
14	0 0 1 0	2	212	Up
15	0 0 0 1	1	199	Down

Table 1. Output sequence of the frequency hopping circuit with associated output frequencies. This group of 15 patterns repeats endlessly.

So, the four-bit shift register provides 15 patterns. A five-bit shift register could provide 31 patterns. A 16-bit shift register could provide 65,535 patterns, none of which are the same, with the entire sequence repeating every 65,535 patterns. That would probably be secure enough.

The inverters are used to provide a little extra current drive to the second 555 timer circuit. The diodes allow the resistors to be connected in parallel whenever the associated inverter output is high. With 15 different output patterns, there will be 15 different combinations of the four frequency resistors, which — in turn — leads to 15 different timing scenarios for the second 555 timer.

Look at Figure 2 to see a student's breadboard of the frequency

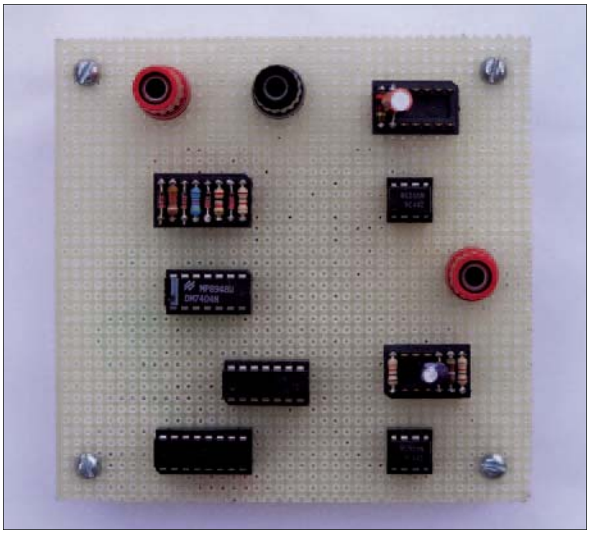


Figure 2. An actual frequency hopping circuit, wire-wrapped on a breadboard.

hopping circuit. In just one afternoon, the student was introduced to the topic during lecture and the circuit was breadboarded and tested in lab.

One problem with the range of generated frequencies in Table 1 is the distribution.

Notice that some frequency changes between output patterns are very small (just 1 Hz between patterns 1 and 2, for example). The four frequency resistors need to be adjusted in this case. The entire set of generated frequencies will change, so a little experimentation or work with the 555 timer equation will be necessary to obtain the desired frequency spread.

One last point deserves mention. What happens if the shift register begins with an initial pattern of 1111? Through the feedback circuit, another 1 will get clocked in, making the next pattern 1111, the same as the last pattern.

This is an illegal state for the pseudo-random sequencer to start in because it can never get out of it. In addition — due to the inverters — there will be no resistance to pin 7 of the second 555 timer, which would prevent oscillation during the 1111 pattern. A power-on reset or some other initialization signal is required to prevent the 1111 pattern from appearing. **NV**

About the Author

James Antonakos is a Professor in the Departments of Electrical Engineering Technology and Computer Studies at Broome Community College. He is also the author of numerous textbooks on those subjects. You may visit his website at ***www.sunybroome.edu/~antonakos_j***

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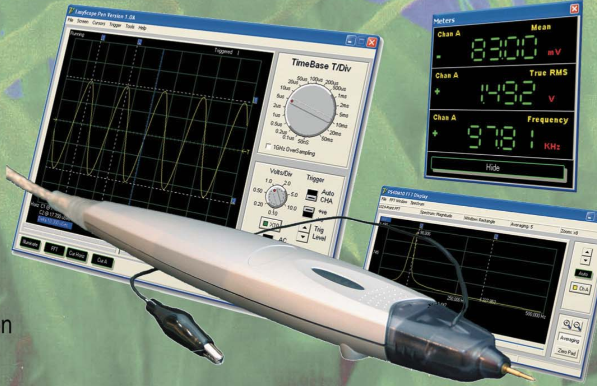

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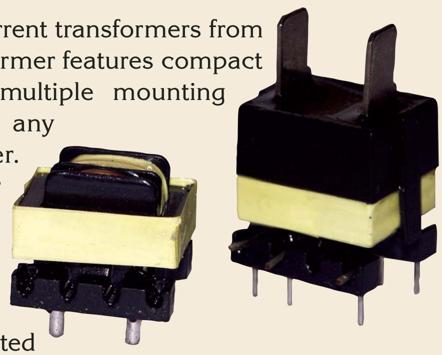
CURRENT TRANSFORMERS FIT SMALL FOOTPRINT WITH VARIOUS MOUNTING OPTIONS



A new line of current transformers from Foster Transformer features compact construction and multiple mounting options to meet any design parameter. They are ideal for use in motor control applications, UPS systems, appliances, or any application where isolated current monitoring is desirable.

Standard models feature a 1:500 turn ratio and handle rated currents from 0.1 to 30.0 amps. Operating frequency range is from 50 Hz to 400 Hz.

Each size and model includes UL Recognized Class 130 (B) insulation. Optional 1/4" quick connect terminals keep high current off of the printed circuit board and simplify connections. Pricing starts at $1.10 each in 1,000 piece quantities.

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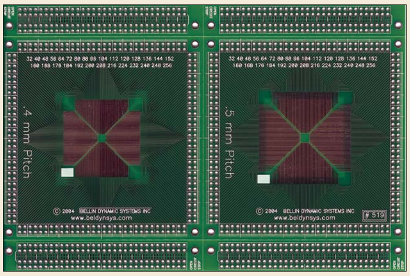
Circle #110 on the Reader Service Card.

UNIVERSAL QUAD SMT ADAPTERS



Bellin Dynamic Systems, Inc., announced the latest Snap-Apart™ adapter board — the P519. The P519 is a Universal Quad Adapter that will work with most SMT Quad ICs on .4 or .5 mm spacing. It is designed to carry Quad ICs with 32 to 256 leads. Each adapter takes SMT Quad chips and breaks out the leads into dual row, .100" header pins. The kit holds one Snap-Apart board with two adapters and eight 80-pin .100" header strips. The P519 is a quick and economical solution to Quad SMT prototyping.

Pictures, product information, and printable data fit check sheets are available at Bellin's website. The P519 is currently available for $59.95 each.

For more information, contact:

BELLIN DYNAMIC SYSTEMS, INC.
211 S. State College Blvd. #319
Anaheim, CA 92806
714-630-8024 Fax: **714-630-8025**
Email: **jsohn@beldynsys.com**
Web: **www.beldynsys.com**

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NEW COMPACT POWER PACKAGE

Diodes Inc., now has available a New PowerDITM5 Compact Power Package which includes the introduction of new high voltage Schottky barrier rectifiers: PDS3200 and PDS5100H. The new PowerDITM5 compact, low profile package — with its patent-pending flat lead frame and heatsink solder pad — offers higher power dissipation and surge capabilities.

The new components occupy only 26.7 mm² of printed circuit board (PCB) area while offering higher power dissipation. It also delivers major improvements for compact applications where circuit board space is at a premium.

With this new product release, Diodes, Inc., continues to extend its product range of subminiature discretes and arrays benefiting automotive devices, power conversion, industrial, server and network applications, and more.

For more information, contact:

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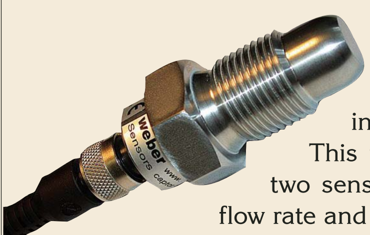
COOLGUARD



Weber Sensors, Inc., announces the introduction of CoolGuard. This first-of-a-kind flow-captor is two sensors in one. It monitors the flow rate and also the temperature of the flowing medium and provides a solidstate switch if flow is lost or temperature is exceeded.

The CoolGuard is solidstate, with no moving parts. In addition, it is the ideal replacement for old fashioned

mechanical flow switches. It won't foul, stick, wear out, or be damaged by excessive flow rates. It can be mounted horizontally or vertically with no effect on the switching point. It has Normally Open "fail safe" switching logic — unlike mechanical switches that often fail, indicating flow is okay when no flow exists. CoolGuard is simple to install and is factory pre-set, so it requires no calibration or adjustment.

Priced right for the OEM as well as the small quantity user, the CoolGuard offers a low cost solution to solidstate flow and temperature monitoring. The CoolGuard — for small quantities — is listed at $195.00. For higher volume quantities, it is less than $100.00. Purchase from their website or by phone.

For more information, contact:

WEBER SENSORS, INC.
2230 Towne Lake Pkwy.
Building 900 #200
Woodstock, GA 30189
Tel: **770-592-6630**
Web: **www.captor.com**

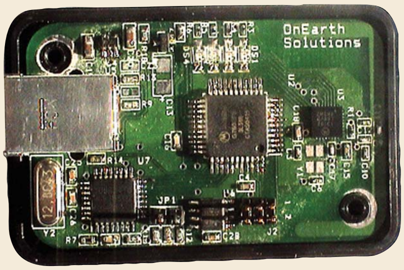
Circle #144 on the Reader Service Card.

COMPLIANT DEVELOPMENT PLATFORM

OnEarth Solutions Corporation is growing as the IEEE 802.15.4 wireless application platform — a precursor to the emerging ZigBee standard — enables them to assist with custom design projects as you develop or add wireless capabilities to existing products.

They currently offer an IEEE 802.15.4-Compliant Development Platform — OES-ZUSB-1000 — which enables customers — in a rapid and cost-effective manner — to design, develop, and ultimately test scalable wireless networks (e.g., peer-to-peer, star, cluster-tree, and mesh) conducive for low data rate transmission, within the rubric of low power consumption (e.g., multi-month/-year battery life).

Additionally, OES-ZUSB-1000 allows for greater ease in adding wireless capabilities to existing products. The OES-ZUSB-1000's hardware, software, and documentation are crafted for personal computer, laptop, or embedded hardware use via its USB Gateway.



Moreover, OES-ZUSB-1000 contributes to reduced risk for developers, as it has the requisite security features to protect data that is transmitted, while also being fairly immune to RF interference. Indeed, the self-replicating capabilities of a wireless network allow for ever-expanding transmission of data carried out over low frequencies with limited interference. The sensors that come with the OES-ZUSB-1000 allow for viewing respective data in a real time basis — all due to the functioning of the wireless networks.

OES-ZUSB-1000's functionality — while allowing for flexibility and greater productivity — is especially geared for developers in applications that require robust and reliable wireless networks with low power usage for monitoring and control over long distances, often without the need for substantial levels of data transmission (e.g., mostly text, graphics, and Internet) for automation and/or control of the ultimate product.

Included with the IEEE 802.15.4-compliant Development Platform, OES-ZUSB-1000 is the following:

- One USB-based 802.15.4 radio transceiver.
- Five battery-operated ready sensors (endpoints), which can be configured as radio repeater/router units.
- Selected sensors.
- Software API and development utilities.

This platform allows for the potential integration of 802.15.4 wireless solutions into existing and prospective products. The IEEE 802.15.4-compliant Development Platform, OES-ZUSB-1000, is available for $2,950.00.

For more information, contact:

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5284 Randolph Rd. #216
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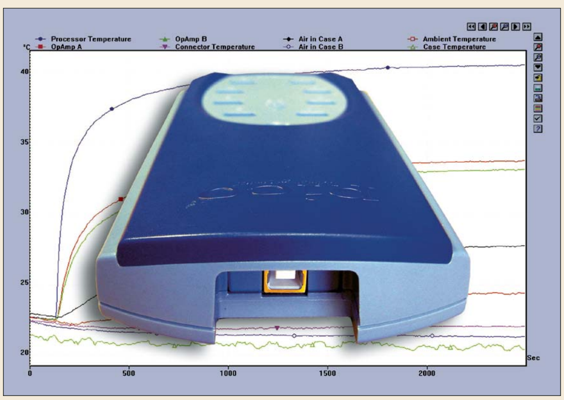
THERMOCOUPLE DATA LOGGER



Pico Technology — the PC-based test and measurement company — has introduced a USB (v1.1) version of its popular TC-08 eight-channel thermocouple data logger. The new unit samples at up to 10 readings per second (more than twice the speed of the serial port version), features built-in cold junction compensation (CJC), and covers the temperature range of -270 to 1,820 degrees C.

The TC-08 can be used with thermocouple types B, E, J, K, N, R, S, and T and outputs can be viewed in degrees C or mV. The unit is accurate to 0.2 percent ±0.5 degrees C and has a resolution of better than 0.1 degrees C for most thermocouple types.

The TC-08's USB connectivity allows multiple units to be run on a single PC, making it easy to create systems with up to 80 thermocouples. The TC-08 is supplied with PicoLog software free of charge. Full and demo versions of the PicoLog software can be downloaded from Pico Technology's website.

Alan Tong, Pico Technology's Technical Director, comments: "The serial version of the TC-08 was launched in 1995 and — with temperature being the most common parameter users wish to measure — quickly became one of our most popular data logging products. However, with serial ports no longer provided on modern PCs, customers had to buy serial-to-USB adapters — but no more. The new TC-08 connects to a PC via USB, dispensing with the need for an adapter and delivering enhanced performance."

With the free PicoLog Recorder software, the user can configure multiple (USB) TC-08s, set the sampling interval from 0.1 seconds to several hours, and set the maximum number of readings. The user can also tell the PicoLog Recorder what to do once the thermocouple readings have been taken. Options include Stop; Repeat Immediately (start again); Scroll (oldest recordings disappear); or Repeat After Delay (where the delay is set by the user). The user can also perform mathematical operations on the thermocouple outputs. For example, the user can output one temperature relative to another.

Using PicoLog Recorder, TC-08 data can be viewed in a spreadsheet and/or in a graph as it is being recorded. TC-08 data collected from previous recordings can also be viewed in PicoLog Player. The TC-08 (USB version) is available immediately and retails for approximately $470.00, plus tax.

For more information, contact:

PICO TECHNOLOGY LTD.
Mill House
Cambridge St.
St. Neots PE19 1QB
United Kingdom
+44 1480 396395 Fax: **+44 1480 396296**
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by Richard Panosh

A Simple Shaded Pole AC Motor

How Could Tesla Be Wrong?

This Month's Projects

The Fuzzball Rating System

To find out the level of difficulty for each of these projects, turn to Fuzzball for the answers.

The scale is from 1-4, with four Fuzzballs being the more difficult or advanced projects. Just look for the Fuzzballs in the opening header.

You'll also find information included in each article on any special tools or skills you'll need to complete the project.

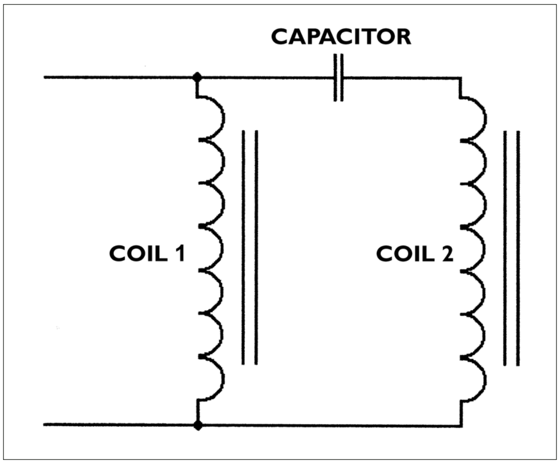
Let the soldering begin!

As early as 1821, Michael Faraday demonstrated that continuous rotary motion could be produced by passing a DC (Direct Current) current through a wire in the presence of a magnetic field.

Many pioneers followed in his footsteps, but failed to develop a commercially successful DC motor. Development was hampered because batteries were the only source of electrical power. Batteries, while large and heavy, were constructed from expensive materials that could provide little energy. As a result, electric power was unable to compete with the current technology — steam power. Steam could be obtained cheaply from just water and coal-fired boilers. Thus, funding for the development of electric motors was nonexistent and they were relegated to being laboratory curiosities.

Further development of electric motors was delayed until the 1870s, when a number of experimenters developed the principle of the self-excited DC generator. At this time, they discovered the reciprocity theorem, in which a motor could act as a generator or vise versa. This discovery was widely publicized in 1873 by the French engineer, Hippolyte Fontaine, who recorded the results of an accident where a worker mistakenly wired two generators together.

Figure 1. A capacitor produces a phase shifted field.



DC generators rapidly replaced the energy deficient batteries with a source of endless electric power. Steam power was now harnessed to drive these generators. The transmission of electric power permitted these plants to be located farther away so that noise and pollution were hidden.

Countless small DC motors were rapidly introduced to power fans, sewing machines, and other light tasks for the upper class. Cities had grown into heavily populated metropolises and a cleaner and cheaper means of transportation was desired to replace the horse-drawn buggy. In 1897, thousands of visitors at Germany's Berlin Exhibition were transported by the first practical electrically-powered motor vehicle, developed by Werner von Siemens.

Many companies began with the production of electrically-powered cars from about 1897 to 1914. In 1898, 23-year-old Ferdinand Porsche landed his first job in the automotive field with Jacob Lohner. He devised a system to eliminate the conventional front wheel hubs, transmission, gears, and chains by installing electric motors integral to each front wheel hub. In 1900, this car made its debut at the World's Fair in Paris, France and went on to set several Austrian land speed records. Porsche realized that the weight and the storage capacity of batteries were serious limitations, but he also recognized the advantage of electric motors to be quiet, smooth, and very reliable. After the exposition, he designed a car that employed an internal combustion engine to drive a generator that, in turn, supplied the electrical power to the twin hub motors. This is a century before Honda, Toyota, and others would introduce their hybrids.

In spite of the great accomplishments, further applications of DC motors were limited since DC power could only be transmitted a

few tens of miles from the generators due to losses in the transmission lines. The advantage that AC (Alternating Current) power could be transmitted over long distances had already been recognized, but its advantage could not be utilized until the AC motor was developed.

DC power design had been rather simple and developed by trial and error. AC power development, however, required a fundamental understanding of AC theory. In 1888, Galileo Ferraris — an Italian professor — published his observations that two out-of-phase light waves would produce a rotating beam of light. From this simple idea, he was led to describe a rotating magnetic field produced by two out-of-phase magnetic fields. In this paper, he described how a single AC current could be split into two out-of-phase components that would produce a traveling magnetic field, but — unfortunately — he erroneously concluded that such a motor was impractical and was only another laboratory curiosity.

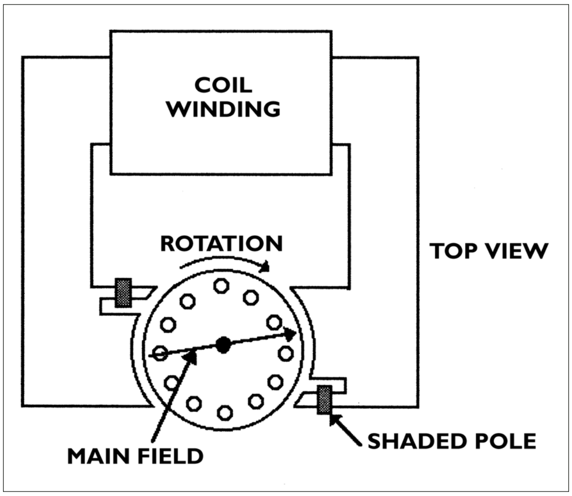


Figure 2. A typical shaded pole motor.

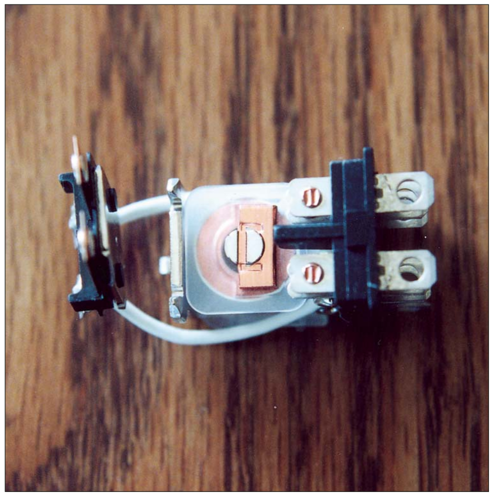


Figure 3. A shaded pole AC relay.

A year earlier, Nikola Tesla (1856-1943) applied for a patent on an AC induction motor that employed a traveling magnetic field that rotated. Tesla was born in Yugoslavia and moved to the US in 1884 to work with Thomas Edison. Unfortunately, the two had a personality conflict and Tesla left Edison a year later to begin an arc lamp business. The conflict between these two inventors continued with Edison pushing for DC systems and Tesla supporting AC systems. During the period of 1888 to 1896, Tesla obtained extensive patent coverage over most of the features of AC motors, including multiphase systems.

By 1893, both Westinghouse and General Electric had introduced AC induction motors. At this time, Tesla demonstrated his system of lighting at the Chicago World Columbian Exposition in the futuristic "White City." The commercial success of AC power was assured in 1896 by the construction of the Niagara Falls hydroelectric plant that provided the staggering power of 11 megawatts. Later, several more generators were added to raise this level to 37 megawatts.

Eventually, this power would enable the Pittsburgh Reduction Company (later to become the Aluminum Company of America) to produce the aluminum that would nurture the aircraft industry. Thus, by the 1900s, all the major features of both DC and AC electric power systems were firmly in place.

In some AC motor designs, two out-of-phase magnetic fields can be generated by the reactive impedance of a capacitor, as illustrated in Figure 1. Such motors are called capacitive motors. One design employs the extra phased winding only for starting torque and these motors are called capacitive start motors. Still another version — the shaded pole motor — produces two out-of-phase magnetic

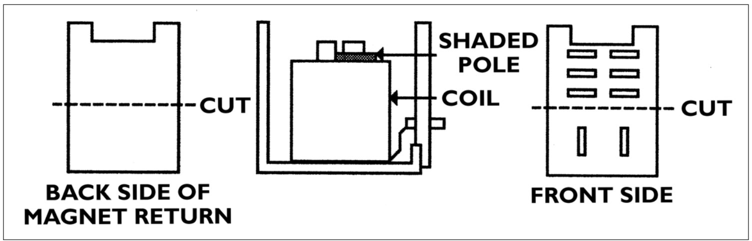


Figure 4. Preparation of the AC coil.

The design of our shaded pole motor starts with two AC relay coils. For ease of construction, the relay coils can be obtained from RadioShack (part number 275-217), but other coils will work. These relays are Omron LY-2-AC 110/120 coils rated at 1.1 VA at 110 to 120 VAC. Typically, the coils draw about 10 mA when the contacts are closed. Some relays operate at 2-3 VA, especially 3PDT and larger relays that will produce larger magnetic fields for larger gaps or that can operate a motor with greater bearing friction. The plastic case, the hinged metal return that supports the contacts, and the return force spring can be discarded.

fields by means of the shading coil. An example of this type is illustrated in Figure 2, where a shorted coil (the shaded pole) encircles part of the magnetic pole. Since the current induced in the shorted turn is a function of the rate of change of the main pole flux, it is out-of-phase and lags the main field.

John Fleming introduced the design of the shaded pole motor around 1890. Fleming would go on to help Guglieimo Marconi design his equipment for the first transatlantic wireless message in 1901 and he would later patent the first vacuum tube (a “thermionic valve”) in 1904. About this same time, Elihu Thomson patented the shaded pole design in the US and, in 1892, his company merged with the Edison General Electric Company to become the General Electric Company.

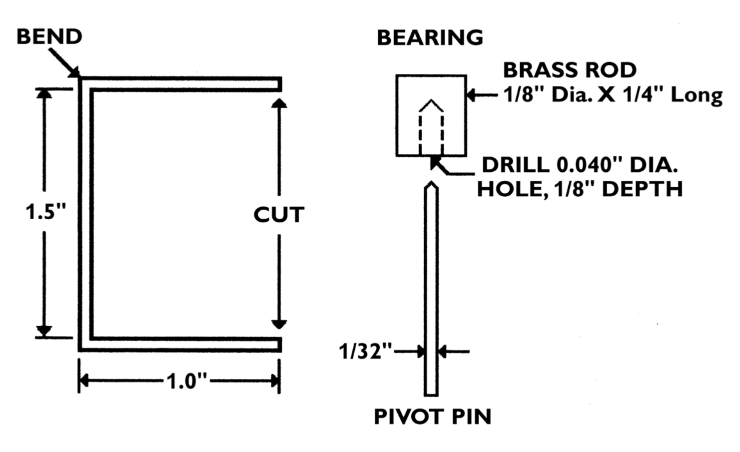
Interestingly, the design of the shaded pole motor to produce a rotating magnetic field is also employed in the design of AC relays and contactors. You can identify AC relay coils from DC designs by looking at the shaded pole, as illustrated in Figure 3. The shaded pole design for AC relays is used to delay one component of the magnetic field to prevent the relay from chattering. Without the shaded pole, an AC relay contact would chatter every time the AC current goes through zero and the magnetic field would be unable to hold the contacts closed against the spring. The delayed field continues to hold the relay contacts closed while the main field goes through zero and visa versa.

Carefully place the coil in a vise and cut the rear of the magnet return down low with a fine-toothed hacksaw blade, as illustrated in Figure 4. As you cut through the steel return, it is advisable to place a 1/16” thick plastic sheet between the steel and the coil to prevent the hacksaw blade from breaking through and damaging the coil. In our application, the magnetic path is essentially through an air gap that reduces the magnetic field and the self-inductance of the coils. This results in larger coil current. The open circuited coil will typically run about 25 ma and will, thus, run thermally warmer.

The plastic terminal block has to be cut down, similar to the metal magnet return, as illustrated in Figure 4. The solder contact just above the relay coil terminals can be removed by unsoldering the attached wires and pulling the pins outward. It is convenient to cut at this same level. Again, it is helpful to put a piece of plastic between the coil and contact block to prevent the saw blade from damaging the coil. Also, use extra caution on this side of the coil because the fine coil leads are also located here.

All the metal parts — including the aluminum sheet, brass sheet, tubing, and rods — were obtained from a hardware store. The magnetic return for the two coils was fabricated from a 3” x 3” x 3/4” steel corner bracket. The bracket was bent in the vise, as illustrated in Figure 5. The spacing is not too critical, but the poles of the coils should be spaced on the order of 3/16”. The coils were epoxied to the steel return using a five minute epoxy, such as Loctite. It is always a good practice to roughen the surfaces to be epoxied with either a file or sandpaper to provide a rough, clean surface for the adhesive. This completes the shaded pole coil assembly.

Figure 5. A steel bracket for magnet return, pivot, and bearing.



The rotor for our motor is fabricated from 1/16” thick aluminum. A compass or divider can be used to inscribe the circle with a 2.5” diameter. A sharp pair of tin snips can be used to cut along the mark to produce the rotor. The main thing is not to distort the aluminum. It must be relatively flat to run between the gap of the pole pieces. Various size rotors have been employed in different designs.

Larger diameter rotors tend to wobble more and may brush against the pole and stop turning. Rotors as thin as 0.003Ž have been made and also work. Material of this thickness can be cut with an ordinary pair of scissors. Thinner material will not work because the resistance of the material becomes too high and the material also becomes mechanically unstable. A 1/8Ž diameter hole can be punched in the rotor at the center of the circle. Either use a hand punch or drill the hole by sandwiching the aluminum between two heavy sheets of plastic to prevent the drill from ripping through.

The central rotor bearing was made from a 1/4Ž long piece of 1/8Ž brass rod, as seen in Figure 5. The rod was drilled with a 0.040Ž diameter drill bit to a depth of 1/8Ž. Most general-purpose drill bits have a 118° point. The central bearing was placed in the central hole of the aluminum rotor and a piece of Scotch tape was placed on the underside to hold the bearing in position and to seal the 0.040Ž hole. Epoxy was applied with a toothpick to glue the bearing and rotor together. Since the mass of the aluminum disc is about 1/8Ž below the support pivot, it will be unconditionally stable and will not fall off the pivot.

As an alternative, some models of this motor have been built using the plastic top of a •three in oneŽ multi-purpose oil can (3 fl oz size) in place of the brass bearing. The closed end of the red plastic spout was cut off with a razor blade about 3/16Ž from the top and used as the bearing. The brass bearing is, of course, more rugged and provides a better bearing if the hole is drilled true. A small lathe is useful here, if you have one.

The pivot point was fabricated from a 1/32Ž brass rod, as shown in Figure 5. The point of the rod was ground by turning the rod against fine emery paper. The rod was held at about a 25° angle above the paper to produce the point. This produces a point of about 50°, as compared to the drill bit point of 118°, to ensure a point of contact and lower friction. In another version of the motor design, a steel needle was used as the pivot point.

The completed motor can be seen in Figure 6. The mounting base was made from a piece of 1/16Ž thick brass that is 4Ž square. A metal base is useful to help dissipate the additional coil heat. At the center of the base, a 4-40 brass nut was soldered. To the center of the nut, a 3/32Ž O.D. brass tube was soldered and the 1/32Ž brass pivot rod was soldered into this tube. The tube helped to stiffen the smaller pivot rod and also allowed less heat to be applied to the pivot rod for adjustment of the height of the pivot to locate the rotor between the pole pieces.

Other models have been built with a wooden base that employed the steel needle pivot mentioned earlier. In such a design, the needle can be pushed further into the wood to adjust the pivot height to center the rotor between the pole pieces.

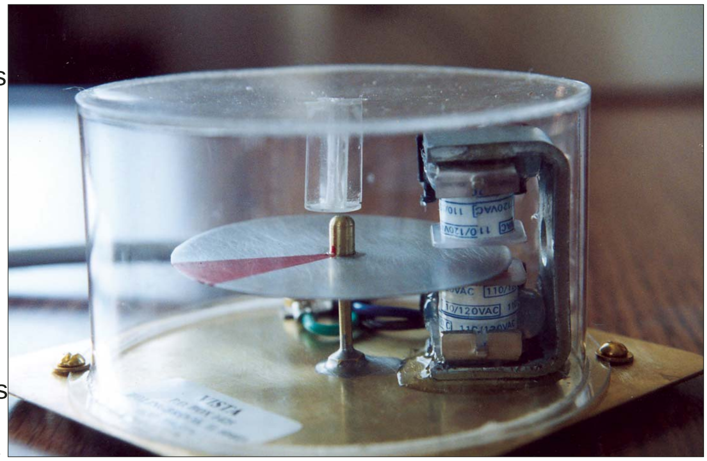


Figure 6. [illegible]

Once the final position has been determined, the pin position can be secured with a drop of epoxy between the base and pin.

After the rotor has been assembled and a pivot rod is available, you can test the bearing and rotor run out. Softly blow on the underside of the disc to see that it spins easily. Also notice if the disc tends to always stop with one side low. It is helpful to mark the rotor with a pen to provide a

reference mark to gauge if the rotor always droops to the same side. If one side is heavier than the other, trim a little off the edge of the rotor that always dips until a reasonable balance is achieved.

The coil assembly is positioned on the base plate so that the rotor passes fully between the pole pieces. The rotor height must be adjusted so that the rotor will spin freely through the pole faces without touching them. When you are sure of the positioning, place some epoxy on the base and locate the coil assembly permanently. Again, be sure the surfaces to be glued are roughened and clean.

Once the coil assembly is secured to the base, the coils may be wired. A thin, 18 gauge appliance cord can be used to supply power. Because the top coil is driven out of phase with the lower coil, the line is connected to pin 7 of the lower coil and pin 8 of the upper coil. Similarly, the neutral is connected to pin 8 of the lower coil and pin 7 of the upper coil.

Because the top coil is turned over from the position of the lower coil, pin 7 of the lower coil is on the same side of pin 8 of the upper coil. The electrical connections should be insulated with silicon rubber sealant placed over all exposed connections. While the motor draws little power, it is connected to 120 VAC and deserves respect. For safety „ if a metal base is employed „ the base should also be electrically grounded through a three-pronged plug.

When the coils are energized, the rotor will spin in the direction of the shaded pole (the shaded pole lags the main field). The rotor speed is about 20 RPM. Very little torque is developed by this design, since the electrons can slip within the aluminum rotor. The 1/16Ž aluminum rotor is heavy enough that a light wind should not bother the operation. Thinner, lighter rotors will require shielding from air currents. An acrylic hemisphere for displaying models or the bottom third of a plastic 2 L soft drink bottle can provide a suitable cover.

The cover for this model was fabricated from a sheet of 0.020Ž Lexan (polycarbonate) that I had available. The 3Ž diameter top circle and lower circular ring were scribed with a compass and cut out with a pair of scissors. These circular pieces are used to form the 2Ž tall strip into a circular tube. The seams were glued with a solvent cement supplied by McMaster Carr Supply Company ( ), part number 7528A13. The top has a support hanging down that is terminated about 1/16Ž above the top of the brass bearing to prevent the rotor from coming off the pivot pin if the motor is jostled around at your next science fair. **NV**

by Peter Best

The Ever-Shrinking µC — Part 2

Six Pins and One MIP — If You Can See It!

If, after reading Part 1 last month, you've been wondering why there are two PIC10F206s on the Little Bits Development Board, here's part of that answer: The inverter pair we just implemented can be tested by simply moving jumpers carrying the desired logic levels between the inverter inputs and watching the inverter outputs on the LEDs. Instead of swapping around jumpers, the second PIC10F206 can be used as stimulus for the first PIC10F206. I wrote a small piece of code called TOGGLER that does nothing but count from 0 to 7 continually. Using jumpers, I feed the output of the PIC10F206 running TOGGLER to the input of the inverter pins of the PIC10F206 running the inverter code. As the count progresses, all of the possible inverter input combinations are provided to the inputs of the inverter pair we realized with the other PIC10F206. The C source for TOGGLER is shown in Listing 3.

I think you have the idea now. So, I've included some C code for a two-input AND gate in Listing 3, as well. There's always more than one way to skin a cat when coding. I've also included an optimized version of the two-input AND gate code in Listing 3 for your approval. From the example code I've presented, you should now be able to create many other logic gates, including a three-input AND gate, an EXCLUSIVE OR/NOR gate, and an OR/NOR gate.

For instance, to fabricate a NAND gate, all you have to do is invert the output levels within the case statements of the AND gate code. An OR gate can be fabricated from the AND gate code by simply changing the output within the case statements to 1 for any case statement that contains a 1 as its argument. To get the NOR function, invert the output of the OR gate within the OR gate case statements.

You can also emulate clocked logic with the PIC10F206 as well, provided that the clocked logic module you're emulating doesn't have more than three output pins. A clocked logic block that immediately comes to mind is the D flip-flop. When clocked, the Q output of a D flip-flop will follow the logic level of the D input with the NOT-Q output complementing the logic level of the D input.

Compile the D flip-flop code in Listing 3 and jumper the D and NOT-Q GPIO pins together. This will divide the incoming clock by 2 and produce the divided clock on the Q output pin. Feed the CLK

***Listing 3**. Remember, the PIC10F206 has a 1 mS instruction cycle time. So, although the logic will work as designed, the logic blocks we emulate with the PIC10F206 won't be as fast as the real thing.*

```
//*********************************************************************
//*  HI-TECH C SOURCE CODE FOR TOGGLER MODULE
//*********************************************************************
void main()
{
 unsigned int x,y;

 TRIS = 0b00001000;      //GP3 input : all others output
 FOSC4 = 0;              //GP2 is an I/O pin
 CMCON  = 0b11110111;    //comparator off:pullups off:wakeup off
 OPTION = 0b11001111;    //prescaler assigned to WDT
 while(1)
 {
  ++GPIO;                //increment output pin set GP0, GP1, GP2
  for(x=0;x<0xFFFF;++x)  //delay by incrementing y 65534 times
   ++y;                  //increment y
 }//while(1)             //loop forever
}//main TOGGLER

//*********************************************************************
//*  HI-TECH C SOURCE CODE FOR 2-INPUT AND GATE MODULE
//*********************************************************************
void main()
{
 TRIS = 0b11111011;      //GP2=output:all other GPIO=input
 FOSC4 = 0;              //GP2 is an I/O pin
 CMCON  = 0b11110111;    //comparator off:pullups off:wakeup off
 OPTION = 0b11001111;    //prescaler assigned to WDT

 while(1)
 {
  switch (GPIO & 0b00000011)
  {
   case 0b00000000:      //GP0 = LOW:GP1=LOW
    GP2 = 0;             //GP2 = LOW
    break;
   case 0b00000001:      //GP0 = HIGH:GP1=LOW
    GP2 = 0;             //GP2 = LOW
    break;
```

(continued)

input of your PIC10F206 D FLIP-FLOP divide-by-2 emulator from one of the three PIC10F206 TOGGLER outputs. You'll see the division of whatever TOGGLER output clock you feed to the CLK input on the Q output of the D flip-flop emulated by the second PIC10F206. Figure 1 (see Part 1 in last month's issue) physically depicts all of the logic we've emulated or talked about so far. The view from way up here is tremendous, isn't it?

Pulse Generation and Signal Conditioning With Little Bits

The 555 is a wonderful device. However, it has its shortcomings, as it programs in an analog fashion rather than a digital one. For instance, it takes a few choice components and some steering diodes to get a true %50 duty cycle pulse train directly from the output of a 555. With the small bit of C in Listing 4 and a single PIC10F206, I've created a 60 Hz pulse train with a 50% duty cycle.

The beginning of the code is very similar to our logic examples, except that the OPTION argument value has now assigned the prescaler to TMR0 (Timer 0) by clearing bit 3 of the OPTION register. Bits 0, 1, and 2 set the prescaler value to 1:64, which instructs TMR0 to increment once every 64 instruction cycles.

The meat of the 60 Hz code is centered on the TMR0 instructions. First, the TMR0 register is loaded with 0x80. After a couple of synchronization cycles, TMR0 begins to count upwards from 0x80. Visualizing this in binary, the first count will be 0b10000001. The second count will be 0b10000010 and so forth until the count reaches 0b11111111 and then rolls over to 0b00000000.

When the count rolls over to 0b00000000, the most significant bit is no longer set and the while(TMR0 & 0x80); becomes false, allowing the code to fall through to the next statement, which is GP2 = 0;. At this point, the code shifts the logic level of GP2 to low and spins in the TMR0 loop, just as it did when GP2 was high. You can alter the frequency of the TMR0-generated pulse train by toying with the three least significant bits of the OPTION register. You can also change the frequency by altering the value loaded to TMR0 and then checking for that value in the following while statement.

(Listing 3, continued)

```
   case 0b00000010:      //GP0 = LOW:GP1=HIGH
    GP2 = 0;             //GP2 = LOW
    break;
   case 0b00000011:      //GP0 = HIGH:GP1=HIGH
    GP2 = 1;             //GP2 = HIGH
    break;
  }//switch
 }//while(1)
}//main

//*********************************************************************
//*  HI-TECH C SOURCE CODE FOR 2-INPUT AND GATE MODULE OPTIMIZED
//*********************************************************************
void main()
{
 TRIS = 0b11111011;      //GP2=output:all other GPIO=input
 FOSC4 = 0;              //GP2 is an I/O pin
 CMCON  = 0b11110111;    //comparator off:pullups off:wakeup off
 OPTION = 0b11001111;    //prescaler assigned to WDT

 while(1)
 {
  switch (GPIO & 0b00000011)
  {
   case 0b00000011:      //GP2=HIGH only if both GP0 and GP1 are HIGH
    GP2 = 1;
    break;
   default:
    GP2 = 0;
    break;
  }//switch
 }//while(1)
}//main

//*********************************************************************
//*  HI-TECH C SOURCE CODE FOR D FLIP-FLOP MODULE
//*********************************************************************
void main()
{
 TRIS = 0b11111100;              //GP0=Q:GP1=NOT-Q:GP2=CLK:GP3=D
 FOSC4 = 0;
 CMCON  = 0b11110111;
 OPTION = 0b11001111;
                                 //power-up clear operation
 while(GP2);                     //wait for CLK to go LOW
 GP0 = 0;                        //set Q
 GP1 = 1;                        //clr Q

 while(1)
 {
  while(!GP2);                   //wait for CLK to go HIGH
  switch (GPIO & 0b00001000)
  {
   case 0b00000000:              //D = 0
    GP0 = 0;                     //clr Q
    GP1 = 1;                     //set NOT-Q
    break;
   case 0b00001000:              //D = 1
    GP0 = 1;                     //set Q
    GP1 = 0;                     //clr NOT-Q
    break;
   }//switch
   while(GP2);                   //wait for clock to go LOW
  }//while(1)                    //loop forever
}//main
```

Listing 4. I'm sure there are some really weird analog things that you can do with a 555, but the PIC10F206 can hold its own against the 555 when it comes to handling and generating pulses.

```
//*************************************************************************
//*  HI-TECH C SOURCE CODE FOR PULSE GENERATOR MODULE
//*************************************************************************
void main()
{

 TRIS = 0b00001000;      //GP3 input : all others output
 FOSC4 = 0;              //GP2 is an I/O pin
 CMCON  = 0b11110111;    //comparator off:pullups off:wakeup off
 OPTION = 0b11000101;    //prescaler assigned to TMR0 @ 1:64

 while(1)                //loop forever
 {
     GP2 = 1;            //GP2 = HIGH
     TMR0 = 0x80;        //load TMR0
     while(TMR0 & 0x80);//count from 0b10000000 to 0b00000000

     GP2 = 0;            //GP2 = LOW
     TMR0 = 0x80;        //load TMR0
     while(TMR0 & 0x80);//count from 0x80 to 0x00
 }//while(1)
}//main

//*************************************************************************
//*  HI-TECH C SOURCE CODE FOR LED DIMMER MODULE
//*************************************************************************

void main()
{
 unsigned char x,y,z;

 TRIS = 0b00001000;      //GP3 input : all others output
 FOSC4 = 0;              //GP2 is an I/O pin
 CMCON  = 0b11110111;    //comparator off:pullups off:wakeup off
 OPTION = 0b11000010;    //prescaler assigned to TMR0 @ 1:8

 y = 0x04;               //initialize y
 z = 0x80;               //initialize z

 while(1)                //loop forever
 {
 do                      //outer do loop
 {
    x=0xFF;

  do                     //inner do loop
  {
     GP2 = 1;            //GP2 = HIGH
     TMR0 = y;           //load TMR0
     while(TMR0 & y);    //count for y time

     GP2 = 0;            //GP2 = LOW
     TMR0 = z;           //load TMR0
     while(TMR0 & z);    //count for z time
   }while(--x);          //do inner loop until x is decremented to 0

    y *= 2;              //multiply y x 2
    z /= 2;              //divide z by 2
  }while(y);             //do outer loop until y = 0

  y = 0x04;              //reinitialize y
  z = 0x80;              //reinitialize z
 }//while(1)
}//main
```

(continued)

It stands to reason that, if we can control the frequency of a pulse train generated by TMR0, we can also control the duty cycle of that pulse train. A %50 duty cycle means that every cycle has equal high and low logic levels with respect to time. If we apply that voltage to an LED, it will be on for half the time and off for half the time. If the frequency is high enough, the LED may appear to be dimmer than it would seem to be when full voltage is applied to it. If we switch between on and off fast enough, our eyes and mind will fool us into thinking that the LED is really never turning off. We can use this phenomenon to our advantage with the second code listing you see in Listing 4.

Let's work our way through the LED dimmer code inside out, beginning with the inner do loop. The GP2 = 1 code is exactly the same as our 60 Hz pulse train generator except that the 0x80 hard-coded value is replaced with a variable of y. The y variable is initialized to a value of 0x04 in the beginning of the code sequence. Recall that the TMR0 register increments every instruction cycle. So, the y count begins at 0b00000100 and ends at 0b00001000 when the TMR0 register rolls over to 0b00001000 from 0b00000111.

Looking at the GP2 = 0 code, it is exactly the same as our previous 60 Hz code for GP2 in a low logic state with the only exception being the variable z holding the 0x80 value, which was loaded right after the y value. What all of this means is that, initially, the high part of the cycle is much smaller than the low part of the cycle with respect to time, which, in turn, says that the LED will initially be off longer than it is on and will appear to be very dim. Each duty cycle period is alive as long as x is not equal to zero. The while(—x) decrements x with each pass through the inner do loop. The outer do loop initializes x, doubles y, and halves z at the completion of each pulse train cycle.

Since y is the variable that determines the high level time of each cycle and z is the variable that determines the low level time of each cycle and the values are approaching each other from the opposite directions, when y is equal to 0b10000000, z will be equal to 0b00000010. At this point, the LED will be at its brightest, since the high part of the cycle (y) will be much longer than the low part of the cycle (z). The

visual effect you will see is the LED going from dim to bright continually.

Delays and pulse trains can also be created with the PIC10F206 by utilizing code similar to that which is used in TOGGLER (Listing 3). Delays that last for seconds can easily be achieved by looping on a for construct like the one used in the TOGGLER code (available at **www.nutsvolts.com**).

Take a look at the voltage booster circuit in Schematic 1 (see Part 1 in last month's issue). The 2N2222A alternately builds and collapses the field formed by the inductor. The steering diode routes the inductor's energy into the 100 µF capacitor. The build-up and collapse of the magnetic field is caused by switching the transistor on and off rapidly with a pulse train provided by a PIC10F206. The code (part of Listing 4) is identical to the 60 Hz pulse train code, except that the TMR0 prescaler is set for 1:2 and the duty cycle of the pulse train is heavily biased to the logic low level. This may, at first, seem backward. However, the energy from the inductor is transferred to the capacitor when the transistor is turned off. When the transistor is on, the inductor is allowed to ramp up a charge.

By rapidly switching the inductor on and off, we are able to feed the inductor's energy through the diode and charge the output capacitor to a voltage that is higher than the input voltage at the inductor. The little circuit you see in Schematic 1, in combination with the voltage booster code in Listing 4, generates about +10 VDC across the output capacitor. You can obtain a much higher voltage by tweaking the pulse train's duty cycle.

(Listing 4, continued)

```
//*********************************************************************
//*  HI-TECH C SOURCE CODE FOR VOLTAGE BOOSTER MODULE
//*********************************************************************
void main()
{

 TRIS = 0b00001000;      //GP3 input : all others output
 FOSC4 = 0;              //GP2 is an I/O pin
 CMCON  = 0b11110111;    //comparator off:pullups off:wakeup off
 OPTION = 0b11000000;    //prescaler assigned to TMR0 @ 1:2

 while(1)                //loop forever
 {
  GP2 = 1;               //GP2 = HIGH
  TMR0 = 0x04;           //load TMR0
  while(TMR0 & 0x04);    //count from 0b00000100 to 0b00001000

  GP2 = 0;               //GP2 = LOW
  TMR0 = 0x80;           //load TMR0
  while(TMR0 & 0x80);    //count from 0x80 to 0x00
 }//while(1)
}//main
//*********************************************************************
//*  HI-TECH C SOURCE CODE FOR ONE-SHOT MODULE
//*********************************************************************
void main()
{
 unsigned int x,y;
 TRIS = 0b00001000;      //GP3 input : all others output
 FOSC4 = 0;              //GP2 is an I/O pin
 CMCON  = 0b11110111;    //comparator off:pullups off:wakeup off
 OPTION = 0b11000111;    //prescaler assigned to TMR0 @ 1:256

 GP2 = 0x00;             //clear GP2
 while(1)                //loop forever
 {
  while(!GP3);           //wait for GP3 to go HIGH
  TMR0 = 0x80;           //debounce the switch closure
  while(TMR0 & 0x80);    //loop for 35mS using TMR0 with prescaler @ 1:256
  GP2 = 1;               //set GP2
  for(x=0;x<0xFFFF;++x)  //delay for one-shot time
   ++y;
  GP2 = 0;               //clear GP2
  while(GP3);            //wait for button release:GP3 to go LOW
  TMR0 = 0x80;           //debounce button release
  while(TMR0 & 0x80);    //loop for 35mS
 }
}
```

In addition to generating pulses, the PIC10F206 can also be programmed to condition pulses. Let's use some TMR0 code we've already written and create a one-shot timer with a built-in switch debouncer. We'll only need a push-button switch and a resistor, as shown by the one-shot section of Schematic 1.

The C code is straightforward. GP3 is the input from the switch/resistor combination. When the switch is open, GP3 is held low by the 20K resistor. The while(!GP3) loops waiting for GP3 to go high. When the switch is closed, GP3 goes high and the TMR0 debounce code is executed; 35 mS later, GP2 goes high and the one-shot delay loop runs. When the one-shot delay loop falls through, GP2 is cleared to a logic low level and — if the switch is still depressed — the while(GP3) statement loops until the push-button is released. The switch is again debounced when released and the one-shot-switch-debounce process repeats from the beginning statement (while(!GP3)).

Now you can see that handling pulse trains and delays with the PIC10F206 is easy to do. So far, we have enabled a crude PWM (Pulse Width Modulation) function with our LED dimmer code and the one-shot code conjures up lots of other possibilities. The same one-shot code could be used to enable a pulse stretcher or pulse shrinker. A missing pulse detector is yet another coding possibility. The bottom line is that precious microcontroller CPU cycles can be offloaded to the PIC10F206 as it can perform mundane tasks, such as debouncing switches and conditioning incoming signals.

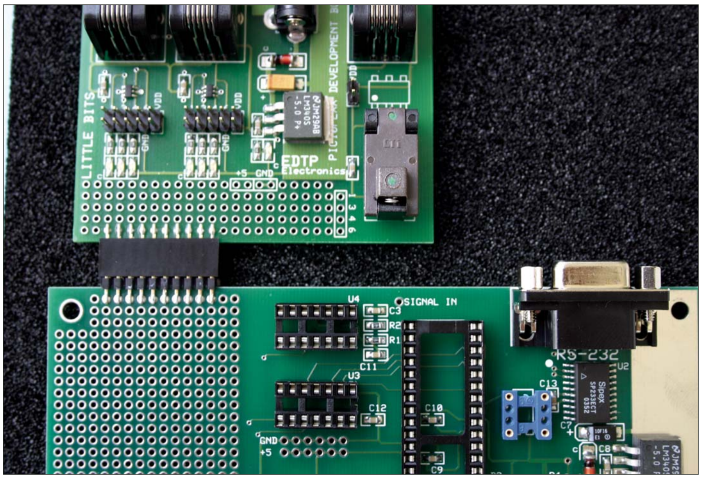


Figure 6. The Digital Filter Development Board is teamed up with a Little Bits to complete the realization of a PIC10F206 bit-bang serial port.

Communicating With Little Bits

There are no USARTs (Universal Synchronous Asynchronous Receiver Transmitters) or UARTs (Universal Asynchronous Receiver Transmitters) contained within the PIC10F206 silicon. So, there's no native PIC10F206 serial communications functionality. Just because the specialized UART hardware doesn't exist doesn't mean we can't implement a software PIC10F206 UART of our own.

In fact, we can do just that and — thanks to the HI-TECH PICC C compiler — we won't have to write any of the serial communications drivers from scratch. All of the bit-bang serial driver code that comes with HI-TECH PICC C compiler is shown in Listing 5. You can study the code in detail if you wish. However, the only things you have to know about the serial driver are the serial functions that you will use when applying the driver code. To send a character, use the putch function. To receive a character, use the getch function. A optional function called getch echoes the incoming character.

This is where the 20-pin female connector I added to my Little Bits comes into play. As you can see in Figure 6, I've called upon a Digital Filter Development Board to aid the Little Bits in getting its serial port operational. I've wired the Digital Filter Development Board's SP233ECT RS-232 IC into one of the PIC10F206 microcontrollers on Little Bits via a 20-pin male header on the Digital Filter Development Board. Only four connections are necessary, with power and ground being givens. Look again at the beginning of the code in Listing 5. You'll see that I've designated GP2 as the transmit pin and GP3 as the receive pin and specified a baud rate of 9600 bps. I've detailed the PIC10F206-to-Digital Filter

Development Board hardware connections in the RS-232 box of Schematic 1.

Now we're ready to send some characters. I set up a Tera Term Pro session on my personal computer and tuned it in for 9600 bps. I then wrote the C code you see at the bottom of Listing 5. The code sends the string NUTS & VOLTS continually. The string I defined at the beginning of my code is actually stored in the PIC10F206's program Flash area and is automatically terminated with a null or zero character by the HI-TECH PICC C compiler.

I've pulled the psect that details how the characters in the string are stored and placed it under my code so you can see how the HI-TECH PICC C compiler handles strings in the Flash memory area. Putting the string in the program Flash memory area is a good thing, as the PIC10F206 doesn't have enough SRAM to hold the string and do other SRAM related things at the same time. Pretty clever, huh?

The null character that signifies the end of the string comes in handy, as I can simply test for it as I send characters

Sources

HI-TECH Software
HI-TECH PICC C compiler
www.htsoft.com

Microchip
MPLAB ICE 2000
PIC10F206
MPLAB IDE
www.microchip.com

EDTP Electronics, Inc.
Little Bits
Digital Filter Development Board
www.edtp.com

Listing 5. This code takes up almost half of the PIC10F206's program Flash. That still leaves enough room to make effective use of the serial port this code creates.

```
// *
// *    Serial port driver (uses bit-banging)
// *    for 16Cxx series parts.
// *
// *    IMPORTANT: Compile this file with FULL opti-
mization
// *
// *    Copyright (C)1996 HI-TECH Software.
// *    Freely distributable.
// *    Adapted for use with the PIC10F20X by Peter
Best

#include<pic.h>
__CONFIG(MCLRDIS & WDTDIS & UNPROTECT);

//Tunable parameters
//Transmit and Receive port bits
#define SERIAL_PORT     GPIO
#define SERIAL_TRIS     TRIS
#define TX_PIN          2       //GP2
#define RX_PIN          3       //GP3

//Xtal frequency
#define XTAL    4000000

//Baud rate
#define BRATE   9600
```

(continued)

(Listing 5, continued)

```
//Don't change anything else
#define SCALER                  10000000
#define ITIME                   4*SCALER/XTAL   // Instruction cycle time
#if BRATE > 1200
 #defineDLY             3               // cycles per null loop
 #defineTX_OHEAD        13              // overhead cycles per loop
#else
 #defineDLY             9               // cycles per null loop
 #define TX_OHEAD               14
#endif
#define RX_OHEAD        12              // receiver overhead per loop

#define DELAY(ohead)            (((SCALER/BRATE)-(ohead*ITIME))/(DLY*ITIME))

static bit      TxData @ (unsigned)&SERIAL_PORT*8+TX_PIN;       // Map TxData to pin
static bit      RxData @ (unsigned)&SERIAL_PORT*8+RX_PIN;       // Map RxData to pin
#define INIT_PORT               SERIAL_TRIS = 1<<RX_PIN         // set up I/O direc-
tion

void putch(char c)
{
 unsigned char  bitno;
 #if BRATE > 1200
  unsigned char dly;
 #else
  unsigned int  dly;
 #endif

 INIT_PORT;
 TxData = 0;                    // start bit
 bitno = 12;
 do
 {
  dly = DELAY(TX_OHEAD);// wait one bit time
   do                           // waiting in delay loop
    while(--dly);
  if(c & 1)
   TxData = 1;
  if(!(c & 1))
   TxData = 0;
  c = (c >> 1) | 0x80;
 }while(--bitno);
 NOP();
}

char getch(void)
{
 unsigned char  c, bitno;
 #if BRATE > 1200
  unsigned char dly;
 #else
  unsigned int  dly;
 #endif

  for(;;)
  {
   while(RxData)
    continue;           // wait for start bit
   dly = DELAY(3)/2;
   do                   // waiting in delay loop
    while(--dly);
   if(RxData)
    continue;           // twas just noise
   bitno = 8;
   c = 0;
```

(continued)

out of the PIC10F206 serial port. Once I encounter a null, I know that I have sent the entire string and I send a carriage return and line feed combination. A simple delay loop is executed and the bit-bang serial process sends another NUTS & VOLTS message.

Good Things in Small Packages

Okay, let's begin our descent and land this thing. As you have seen, lots of useful things can be done with a tiny PIC10F206, its four I/O lines, and a good C compiler like the HI-TECH PICC C compiler. The air is really clear at 23,000 feet. You have seen for yourself that using a C compiler with a tiny PIC like the PIC10F206 is not necessarily a bad thing.

Whether you code in assembler or C, the PIC10F20X series of micro-controllers is a blast to work with. I'm sure you'll want to try your hand at some tiny applications, as well. So, I'll make all of the Little Bits code in the listings available for download from the *Nuts & Volts* FTP server (**www.nutsvolts.com**).

For those of you who want to melt some solder around a PIC10F206, either the Wahl Iso Tip portable soldering iron with a 7566-100 micro tip or a Metcal Soldering Station with a SSC-645A soldering element is perfect for the task. If you don't want to roll your own Little Bits, you can get a kit of parts or an assembled Little Bits unit from EDTP Electronics (**www.edtp.com**). **NV**

(Listing 5, continued)

```
   do
   {
    dly = DELAY(RX_OHEAD);
    do                  // waiting in delay loop
     while(--dly);
    c = (c >> 1) | (RxData << 7);
   }while(--bitno);
   return c;
  }
}

char getche(void)
{
 char c;

 putch(c = getch());
 return c;
}

//*********************************************************************
//*  HI-TECH C SOURCE CODE FOR RS-232 MODULE
//*********************************************************************

const char * string = "NUTS & VOLTS";

void main()
{
 unsigned char x;
 unsigned int y,z;

 FOSC4 = 0;
 CMCON  = 0b11110111;
 OPTION = 0b11001111;

 while(1)                      //loop forever
 {
  x = 0;                       //initialize character index
  do
  {
   putch(string[x++]);         //send character indexed by x: increment x
  }while(string[x] != 0); //look for null character at end of string
  putch(0x0D);                 //send carriage return
  putch(0x0A);                 //send line feed
  for(y=0;y<0xFFFF;++y)        //delay for a while
   ++z;
 }
}
//*********************************************************************
//*  HOW THE STRING IS STORED IN FLASH
//*********************************************************************
   248                                  psect    strings
   249  018                       u19
   250  018   84E                       retlw    78      ;'N'
   251  019   855                       retlw    85      ;'U'
   252  01A   854                       retlw    84      ;'T'
   253  01B   853                       retlw    83      ;'S'
   254  01C   820                       retlw    32
   255  01D   826                       retlw    38      ;'&'
   256  01E   820                       retlw    32
   257  01F   856                       retlw    86      ;'V'
   258  020   84F                       retlw    79      ;'O'
   259  021   84C                       retlw    76      ;'L'
   260  022   854                       retlw    84      ;'T'
   261  023   853                       retlw    83      ;'S'
   262  024   800                       retlw    0
```

by Mark Dobrosielski

Calculating Current

Limiting Resistor Values for LED Circuits

An LED is one of those product components that just has to work. If I look at my computer from across the room and don't see its LED winking back at me, I assume it's turned off; I never expect that the LED might have burned out. There's good reason for that: When operated within specs, an LED has a lifetime of 100,000 hours or more.

The key to maximizing LED life is limiting the current that runs through it. This is frequently done with a simple resistor whose value is calculated using Ohm's Law. This article reviews how to apply Ohm's Law to single and clustered LED circuits. I have also provided an Excel spreadsheet to simplify — and speed up — the process.

Single LEDs

When computing the value of a current limiting resistor for a single LED, the basic form of Ohm's Law — V = IR — becomes:

$$R = \frac{V_{batt} - V_{led}}{I_{led}}$$

where:

V_{batt} is the voltage across the resistor and the LED.
V_{led} is the forward voltage of the LED.
I_{led} is the forward current of the LED.

Figure 1(a) shows an example of a single LED circuit. Incidentally, V_{batt} - V_{led} is the voltage drop across the resistor, and $(I_{led})^2R$ is the power dissipated by the resistor. Calculating the power dissipation is a step that many people — hobbyists and professionals alike — tend to skip. So, what do you call a 1/8 W resistor that needs to dissipate 1/2 W? Charcoal.

LEDs in Series

The equation above gets only slightly more complicated when you connect multiple LEDs in series. The voltage drop across the LEDs increases, reducing the voltage drop across the resistor. The current through the resistor (and the LEDs) remains the same:

$$R = \frac{V_{batt} - nV_{led}}{I_{led}}$$

where n is the number of LEDs in series. Figure 1(b) shows an example with three LEDs connected in series. The voltage drop across the LEDs is three times the voltage drop of a single LED.

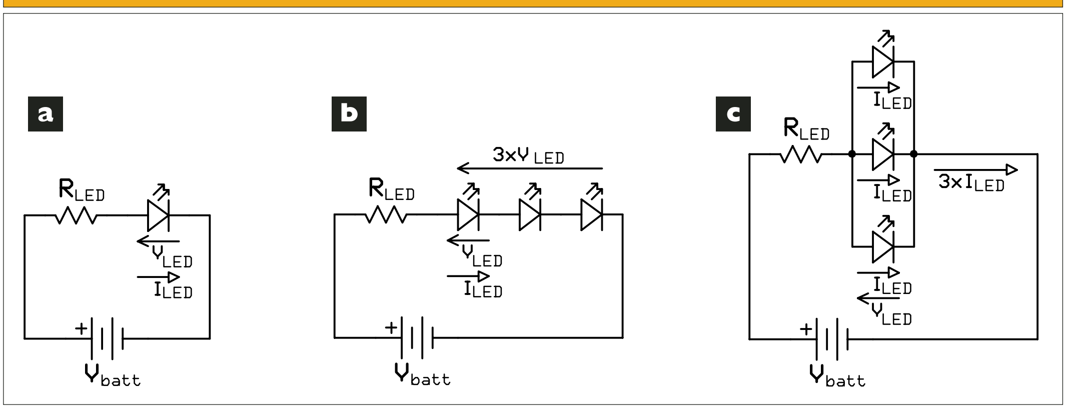
LEDs in Parallel

If you connect multiple LEDs in parallel, the current through the resistor increases (though the current through each LED remains the same). The voltage drop across the LEDs is unaffected, as is the voltage drop across the resistor:

$$R = \frac{V_{batt} - V_{led}}{mI_{led}}$$

where m is the number of LEDs in parallel. Figure 1(c) shows an example with three LEDs connected in parallel. The current through the circuit is three times the current of a single LED.

Figure 1. Simple LED circuits. (a) Single LED circuit. (b) LEDs in series. (c) LEDs in parallel.



LED Arrays

If you connect multiple LEDs in an array,

you just need to combine the serial and parallel forms of the equations:

$$R = \frac{V_{batt} - nV_{led}}{mI_{led}}$$

It's important that there are n LEDs (connected in series) in each of the m parallel branches of the circuit and that the LEDs all have the same V_{led} and I_{led}. Otherwise, all bets are off. Figure 2(a) shows four LEDs connected in such a way that the previous equation does not apply. Figure 2(b) shows one of several "proper" ways to connect four LEDs.

Brightness Control

Brightness control is useful for gadgets that might be used under different ambient lighting conditions (outside/inside, night/day, etc.). This feature requires two resistors — one fixed (R_f) and one variable (R_v). R_f limits the current when R_v is at its minimum setting — usually 0 Ω — which allows maximum current to flow through the LED. The value of R_f is calculated when R_v = 0:

$$R_f = \frac{V_{batt} - nV_{led}}{mI_{led(max)}}$$

where Iled(max) is the maximum current you want through the LED.

Increasing the R_v setting adds resistance to the circuit, decreasing the current through the LED. When R_v is at its maximum setting, the minimum amount of current flows through the LED. The value of R_v is given by:

$$R_v = \frac{V_{batt} - nV_{led}}{mI_{led(min)}} - R_f$$

where $I_{led(min)}$ is the minimum current you want through the LED.

Design Steps

There are four steps to selecting the proper current limiting resistor value(s):

• Using the desired operating characteristics and LED specs, solve the appropriate equations for the

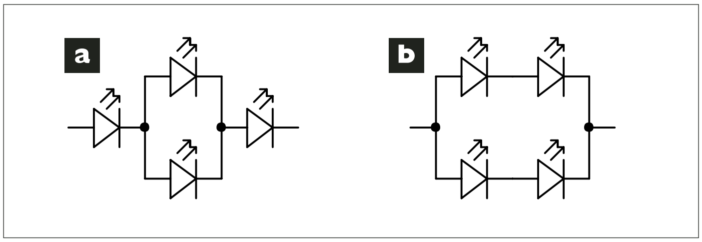


Figure 2. LED arrays.

"ideal" resistor values.

• Select appropriate "real" resistor values. If the calculations specify a 132.27 Ω resistor, the nearest "real" resistor values are 130 Ω and 150 Ω (5% tolerance). Of course, you could select other values based on what you have on hand.

• Plug the values of the resistors you selected back into the calculations to see if they will satisfy the desired operating characteristics.

• Run through the calculations using the selected resistor values at the extremes of tolerance. A 150 Ω resistor with 5% tolerance can range from 142.5 Ω to 157.5 Ω and will seldom be precisely 150 Ω. Also, calculate the current draw of the circuit and the necessary power dissipation of the resistors.

Some folks don't go through any of these steps and just guess at a value. Most go through the first two steps, which is usually fine — as long as you don't operate too close to the LED's limits, where tolerances can push you over the edge. By following all four steps, you can guarantee that your LEDs, at least, are operating safely and should last a good long time.

Multiple Iterations Are a Drag

Calculating the proper resistors for LED circuits is pretty simple. It takes just a few moments, even when going through all four design steps. That's no big deal, if

Figure 3. Brightness control.

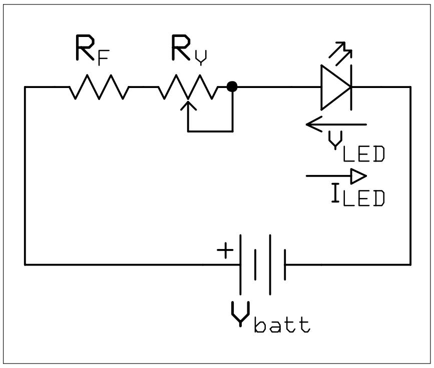
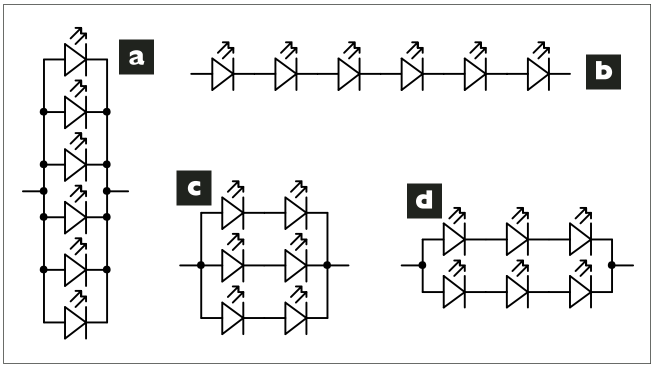


Figure 4. Ways to connect six LEDs.



LED Resistor Calculator

Mark V. Dobrosielski   mdobrosielski@ieee.org

Circuit characteristics

Parameter	Value		
V_{batt}	**5.0**	V	Battery voltage
V_{led}	**1.9**	V	LED forward voltage
$I_{led(max)}$	**2.0**	mA	Max desired LED current
$I_{led(min)}$	**2.0**	mA	Min desired LED current
# leds/branch	**1**		# LEDs in series
# branches	**1**		# LEDs in parallel

Calculated (ideal) I & R values and suggested (real) resistor values

Parameter	Value		
$R_{f(ideal)}$	1550.0	ohm	Calculated fixed resistor value
$R_{v(ideal)}$	0.0	ohm	Calculated variable resistor value
$I_{max(ideal)}$	2.0	mA	Max current using calculated resistor values
$I_{min(ideal)}$	2.0	mA	Min current using calculated resistor values
$R_{f(real)}$	1600	ohm	Corresponding "real" fixed resistor value
$R_{v(real)}$	0	ohm	Corresponding "real" variable resistor value

Calculated circuit performance using selected resistors

Parameter	Value		Tolerance		
R_f	**1600**	ohm	**5.0**	%	Selected fixed resistor value & tolerance
R_v	**0**	ohm	**10.0**	%	Selected variable resistor value & tolerance
I_{max}	2.0	mA			Max current using selected resistors with worst-case tolerance
I_{min}	1.8	mA			Min current using selected resistors with worst-case tolerance
I_{batt}	2.0	mA			Peak current battery needs to supply
P_f	0.01	W			Power dissipated by fixed resistor at peak current
P_v	0.00	W			Power dissipated by variable resistor at peak current

Figure 5. View of the spreadsheet.

you only have to do it once, but what if you want to see the effect of different resistors in the circuit? What if you have an array of LEDs and you want to determine the best way to hook them up? (Figure 4 illustrates four ways to connect six LEDs.) The calculations are still simple; you just have to do them a bunch more times. That gets tedious and that's exactly when people tend to make mistakes.

To beat the tedium and the mistakes that go with it, I've put together an Excel spreadsheet that performs all the necessary calculations — including looking up "real" resistor values. It's a real time saver!

Using the Spreadsheet

The spreadsheet (available on the *Nuts & Volts* website at **www.nutsvolts.com**) is broken down into three sections. The first section, Circuit Characteristics, is where you enter your circuit parameters. The second section, Calculated I & R Values and Suggested Resistors, calculates the needed resistor values and suggests "real" resistors to use in the circuit. The last section, Calculated Performance Using Selected Resistors, lets you plug in resistor values (the suggested values or values of your own choosing) and calculates LED currents, power supply currents, and resistor power dissipation. It also takes into account resistor tolerance. *Note: Values in blue boldface are the only ones you should change. Plain black text shouldn't be changed.* **NV**

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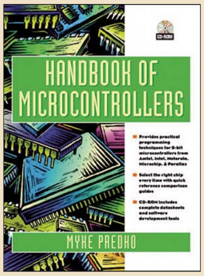

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Robot DNA Series: Programming Robot Controllers
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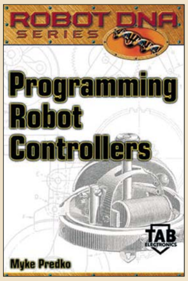

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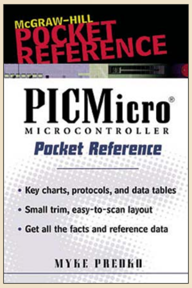

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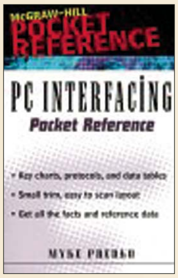

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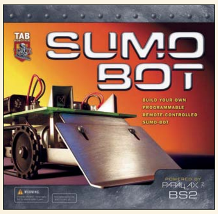

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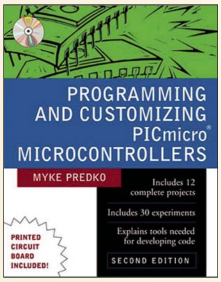

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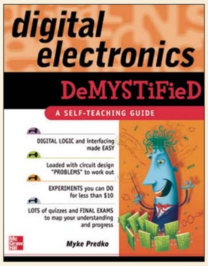
by Myke Predko



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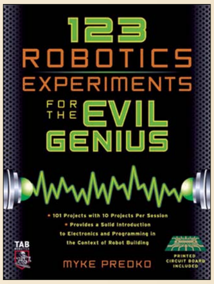

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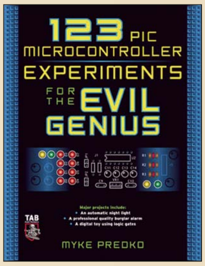

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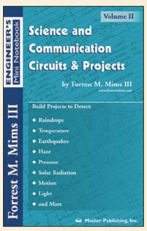

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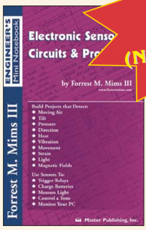

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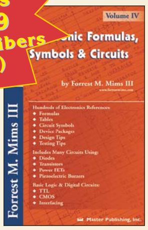

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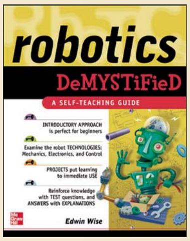

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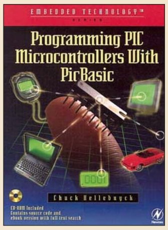

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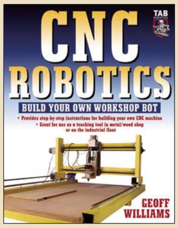

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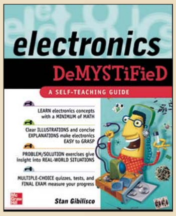

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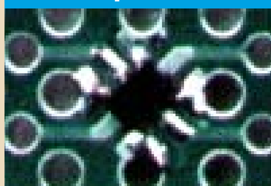

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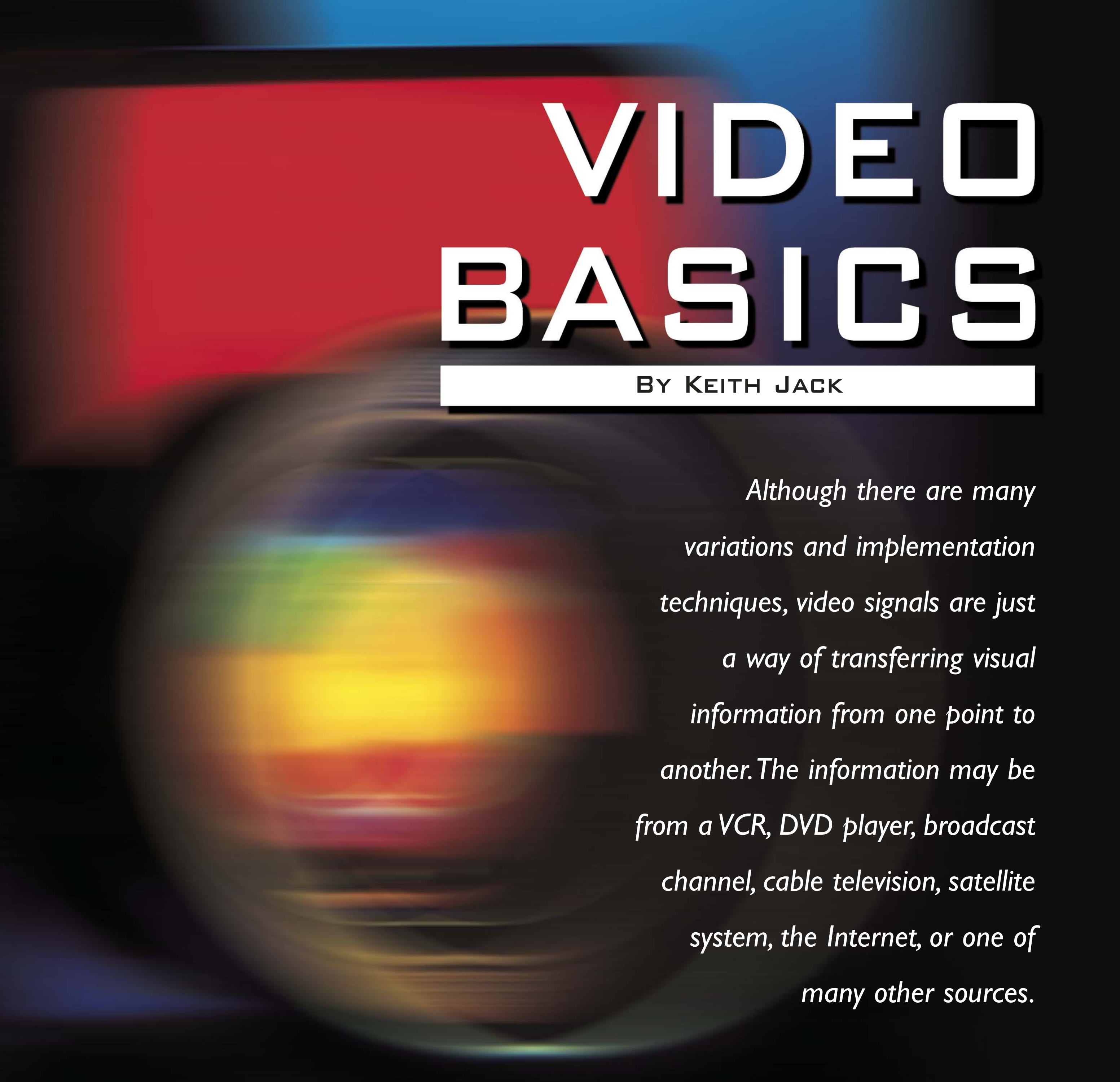


VIDEO BASICS

BY KEITH JACK

Although there are many variations and implementation techniques, video signals are just a way of transferring visual information from one point to another. The information may be from a VCR, DVD player, broadcast channel, cable television, satellite system, the Internet, or one of many other sources.

Invariably, video information must be transferred from one device to another. It could be from a satellite set-top box or DVD player to a television — or it could be from one chip to another inside the satellite set-top box or television. Although it seems simple, there are many different requirements and, therefore, many different ways of doing it.

Until a few years ago, most consumer video equipment supported only analog video. Digital video was confined to professional applications, such as video editing.

The average consumer now uses digital video every day, thanks to continually falling costs. This trend has led to the development of DVD players and recorders, digital set-top boxes, digital television (DTV), portable video players, and the ability to use the Internet for streaming video data.

Video Data

Initially, video contained only Y or grayscale (also called black-and-white) information.

While color broadcasts were being developed, attempts were made to transmit color video using analog RGB (Red, Green, Blue) data. However, this

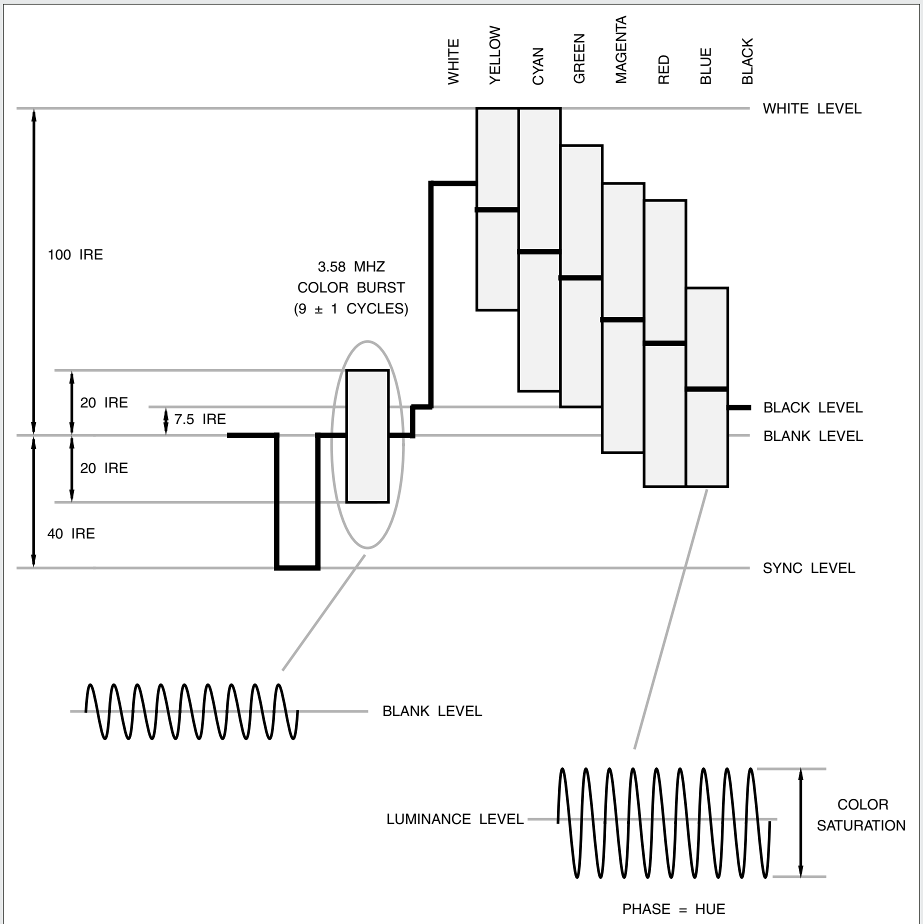


FIGURE 1. NTSC COMPOSITE VIDEO SIGNAL FOR 75% COLOR BARS.

technique occupied 3x more bandwidth than the current grayscale solution, so alternate methods were developed that led to using Y, U, and V data to represent color information. A technique was then developed to transmit this Y, U, and V information using one signal — instead of three separate ones — in the same bandwidth as the original grayscale video signal. The general relationship between YUV and gamma-corrected RGB (R´G´B´) is:

$$Y = 0.299R' + 0.587G' + 0.114B'$$
$$U = -0.147R' - 0.289G' + 0.436B' = 0.492(B' - Y)$$
$$V = 0.615R' - 0.515G' - 0.100B' = 0.877(R' - Y)$$

$$R' = Y + 1.140V$$
$$G' = Y - 0.395U - 0.581V$$
$$B' = Y + 2.032U$$

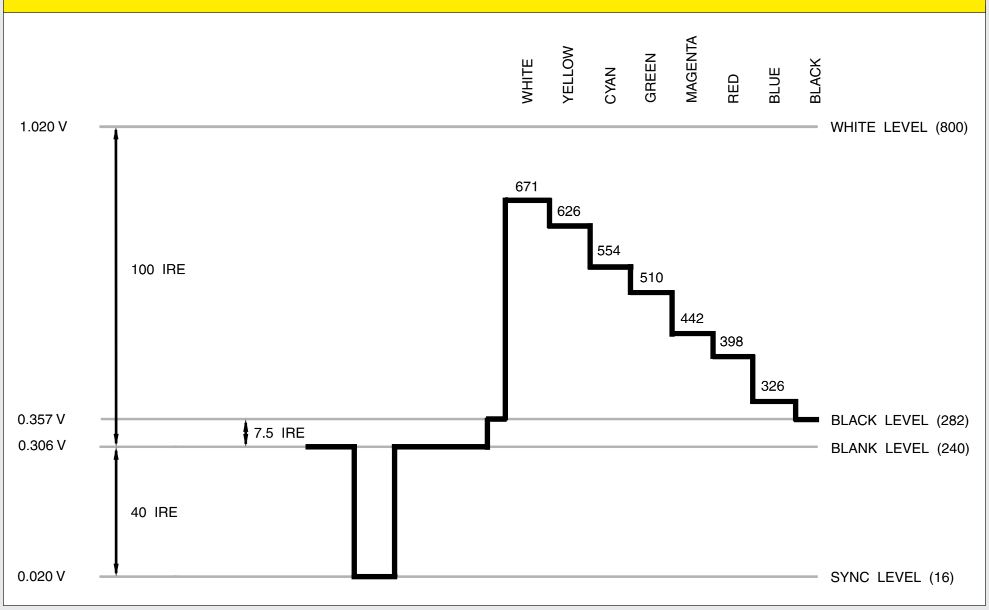
In order to transmit the color information so that black-and-white televisions would still display the grayscale image, the color information (U and V) is modulated onto a 3.58 MHz (NTSC) or 4.43 MHz (PAL) subcarrier and added to the grayscale video signal.

composite color video = Y + U sin wt + V cos wt + timing

w = 2pFsc

Fsc = ~3.58 MHz for NTSC; ~4.44 MHz for PAL

FIGURE 2. NTSC LUMINANCE (Y) VIDEO SIGNAL FOR 75% COLOR BARS. INDICATED LUMINANCE LEVELS ARE 10-BIT VALUES.



The resulting NTSC composite video signal (Figure 1) is what the NTSC, PAL, and SECAM video standards are still based on today.

S-video was later developed for connecting consumer equipment together (it is not used for broadcast purposes). It is a set of two analog signals — the grayscale (Y) signal (shown in Figure 2) and the chroma (C) signal that carries the U and V color information in a specific format (shown in Figure 3). Note that if Y and C are added together, the result is a composite video signal. Once available only for S-VHS, S-video is now supported

on most consumer video products.

Although always used by the professional video market, analog RGB video data has made a temporary come-back for connecting high end consumer equipment together. Like S-video, it is not used for broadcast purposes.

A variation of the analog YUV video signals called YPbPr — illustrated in Figure 4 — is now commonly used for connecting consumer video products together. Its primary advantage is the ability to transfer high definition video between consumer products. Some manufacturers also label these YPbPr connectors as YUV, YCbCr, or Y(B-Y)(R-Y).

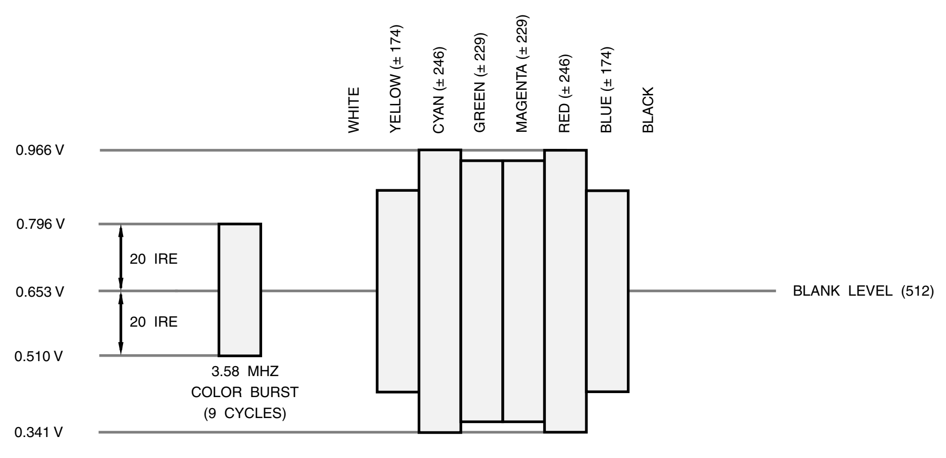


FIGURE 3. (M) NTSC CHROMINANCE (C) VIDEO SIGNAL FOR 75% COLOR BARS. INDICATED VIDEO LEVELS ARE 10-BIT VALUES.

Video Timing

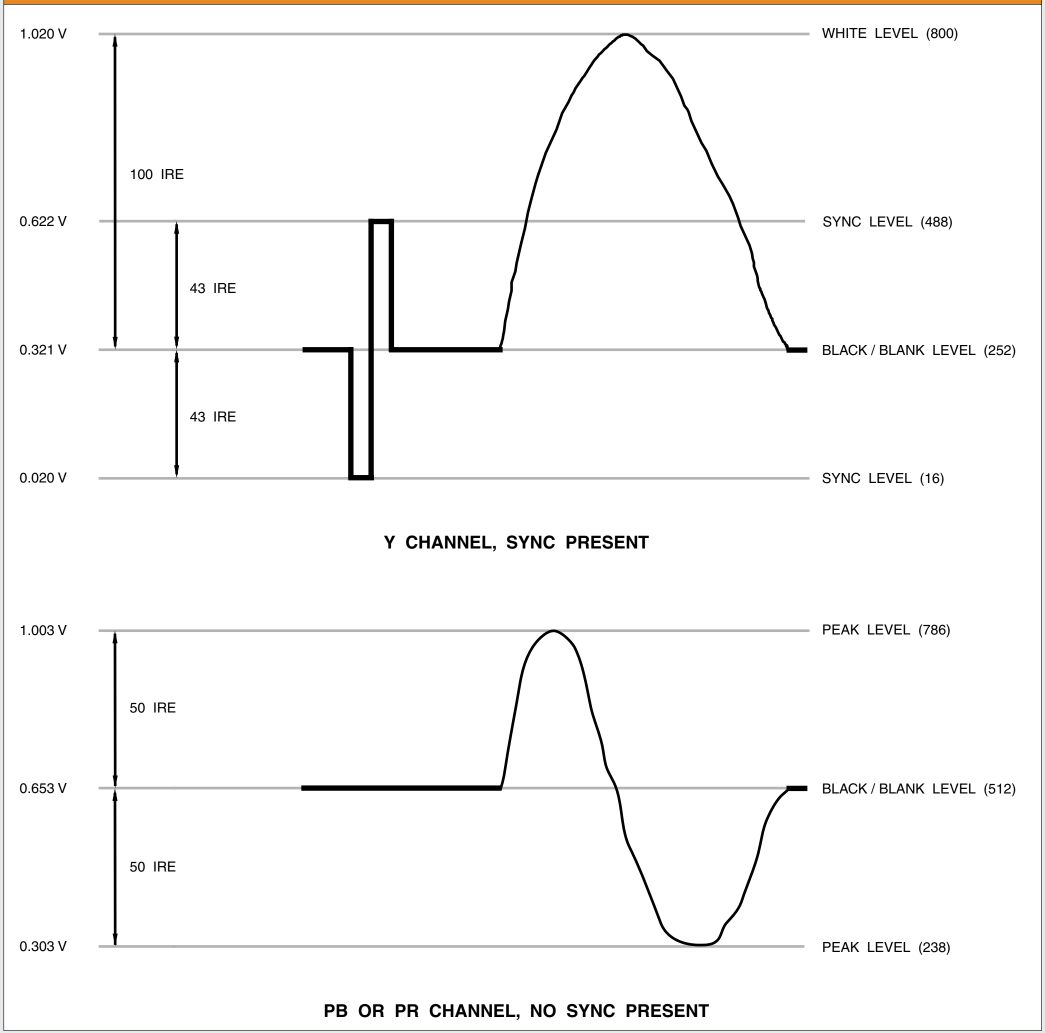
Although it looks like video is in continuous motion, it is actually a series of still images, changing fast enough that it looks like continuous motion, as shown in Figure 5. This typically occurs 50 or 60 times per second for consumer video and 60–90 times per second for computer displays. Special timing information known as vertical sync is used to indicate when a new image is starting.

Each still image is also composed of scan lines — lines of data that occur sequentially, one after another, down the display, as shown in Figure 6. Additional timing information — horizontal sync — is used to indicate when a new scan line is starting. The vertical and horizontal sync information is usually transferred in one of three ways:

1. Separate horizontal and vertical sync signals
2. Separate composite sync signal
3. Composite sync signal embedded within the video signal

The composite sync signal is a combination of both vertical and horizontal sync. Computer and consumer equipment that uses analog RGB video usually uses technique 1 or

FIGURE 4. HDTV ANALOG YPBPR VIDEO SIGNAL.



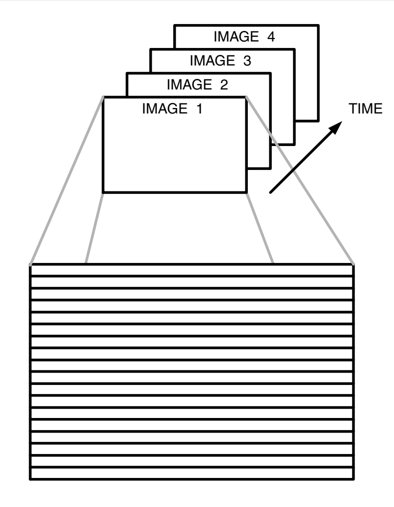


FIGURE 5. VIDEO IS COMPOSED OF A SERIES OF STILL IMAGES. EACH IMAGE IS COMPOSED OF INDIVIDUAL LINES OF DATA.

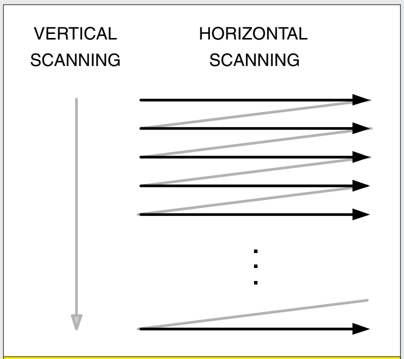


FIGURE 6. PROGRESSIVE DISPLAYS "PAINT" THE LINES OF AN IMAGE CONSECUTIVELY, ONE AFTER ANOTHER.

2. Consumer equipment that supports composite video or analog YPbPr video usually uses technique 3. For digital video, either technique 1 is commonly used or timing code words are embedded within the digital video stream.

Interlaced vs. Progressive

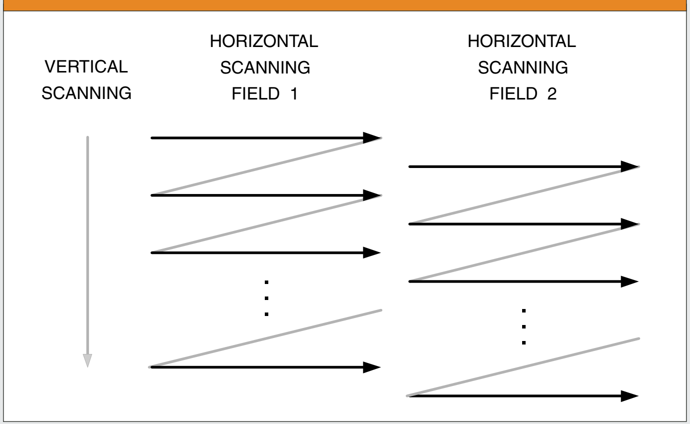
Since video is a series of still images, it makes sense to simply display each full image consecutively, one after the another. This is the basic technique of progressive — or non-interlaced — displays. For progressive displays that "paint" an image on the screen (such as a CRT), each image is displayed starting at the top left corner of the display, moving to the right edge of the display. The scanning then moves down one line and repeats scanning left-to-right. This process is repeated until the entire screen is refreshed, as seen in Figure 6.

In the early days of television, a technique called "interlacing" was used to reduce the amount of information sent for each image. By transferring the odd-numbered lines followed by the even-numbered lines (as shown in Figure 7), the amount of information sent for each image was halved. Given this advantage of interlacing, why bother to use progressive?

With interlace, each scan line is refreshed half as often as it would be if it were a progressive display. Therefore, to avoid line flicker on sharp edges due to a too-low refresh rate, the line-to-line changes are limited, essentially by vertically lowpass-filtering the image. A progressive display has no limit on the line-to-line changes, so it is capable of providing a higher resolution image (vertically) without flicker.

Today, most broadcasts (including HDTV) are still transmitted as interlaced. Most CRT-based televisions are still interlaced, while LCD, plasma, and computer displays are progressive.

FIGURE 7. INTERLACED DISPLAYS FIRST "PAINT" ONE HALF OF THE IMAGE (ODD LINES), THEN THE OTHER HALF (EVEN LINES).



Digital Video

The most common digital video signals used are RGB and YCbCr. RGB is simply the digitized version of the analog RGB video signals. YCbCr is basically the digitized version of the analog YPbPr video signals and is the format used by DVD and the various terrestrial, cable, and satellite digital television standards (ATSC, DVB, and ISDB).

Not too long ago, DVI was introduced to consumer products for transferring digital RGB video between components. In 2004, the trend has shifted to using HDMI, which has the advantage of a smaller connector, the ability to transfer digital audio, and the ability to support both the RGB and YCbCr digital video formats.

Best Connection Method

There is always the question, "What is the best connection method for equipment?" For DVD players and digital cable/satellite/terrestrial set-top boxes, the typical order of decreasing video quality is:

1. HDMI (digital YCbCr)
2. HDMI/DVI (digital RGB)
3. Analog YPbPr
4. Analog RGB
5. Analog S-video
6. Analog Composite

Some may disagree about the order. However, most consumer products do digital video processing in the YCbCr color space. Therefore, using YCbCr as the interconnect for equipment reduces the number of color space conversions required. Color space conversion of digital signals is still preferable to D/A (digital-to-analog) conversion, followed by A/D (analog-to-digital) conversion, hence the positioning of DVI above analog YPbPr.

Video Resolution

Video resolution is one of those “fuzzy” things in life. It is common to see video resolutions of 720 x 480 or 1,920 x 1,080. However, those are just the number of horizontal samples and vertical scan lines and do not necessarily convey the amount of useful information.

For example, an analog video signal can be sampled at 13.5 MHz to generate 720 samples per line. Sampling the same signal at 27 MHz would generate 1,440 samples per line. However, only the number of samples per line has changed, not the resolution of the content.

Therefore, video is usually measured using “lines of resolution.” In essence, how many distinct black-and-white vertical lines can be seen across the display? This number is then normalized to a 1:1 display aspect ratio (dividing the number by 3/4 for a 4:3 display or by 9/16 for a 16:9 display). Of course, this results in a lower value for widescreen (16:9) displays, which goes against intuition.

Standard Definition

Standard definition video is usually defined as having 480 or 576 interlaced active scan lines and is commonly called 480i or 576i, respectively.

For a fixed-pixel (non-CRT) consumer display with a 4:3 aspect ratio, this translates into an active resolution of 720 x 480i or 720 x 576i. For a 16:9 aspect ratio, this translates into an active resolution of 960 x 480i or 960 x 576i.

Enhanced Definition

Enhanced definition video is usually defined as having 480 or 576 progressive active scan lines and is commonly called 480p or 576p, respectively.

For a fixed-pixel (non-CRT) consumer display with a 4:3 aspect ratio, this translates into an active resolution of 720 x 480p or 720 x 576p. For a 16:9 aspect ratio, this translates into an active resolution of 960 x 480p or 960 x 576p.

The difference between standard and enhanced definition is that standard definition is interlaced, while enhanced definition is progressive.

High Definition

High definition video is usually defined as having 720 progressive (720p) or 1,080 interlaced (1,080i) active scan lines. For a fixed-pixel (non-CRT) consumer display with a 16:9 aspect ratio, this translates into an active resolution of 1,280 x 720p or 1,920 x 1,080i, respectively.

However, HDTV displays are technically defined as being capable of displaying a minimum of 720p or 1,080i active scan lines. They also must be capable of displaying 16:9 content using a minimum of 540 progressive (540p) or 810 interlaced (810i) active scan lines. This enables the manufacturing of CRT-based HDTVs with 4:3 aspect ratios and LCD/plasma 16:9 aspect ratio displays with resolutions of 1,024 x 1,024p, 1,280 x 768p, 1,024 x 768p, and so on, lowering costs.

Audio and Video Compression

The recent advances in consumer electronics — such as digital television, DVD players and recorders, digital video recorders, and so on — were made possible due to audio and video compression based largely on MPEG-2 video with Dolby® Digital, DTS®, or MPEG audio. New audio codecs (such as MPEG-4 HE-AAC and WMA Pro) and new video codecs (such as H.264 and SMPTE VC-1) offer much better compression than legacy codecs for the same quality. These advances are enabling new ways of distributing content (both to consumers and within the home), new consumer products (such as portable video players and mobile video/cell phones), and more cable/satellite channels. **NV**

ABOUT THE AUTHOR

Keith Jack is the author of Video Demystified *and Director of Product Marketing at Sigma Designs, a leading supplier of Digital Media Processors that provides high quality processing of H.264, WMV9/VC-1, MPEG-4, MPEG-2, MPEG-1, and content. In his previous career in marketing and chip design, he was involved in bringing over 30 multimedia chips to the consumer market.*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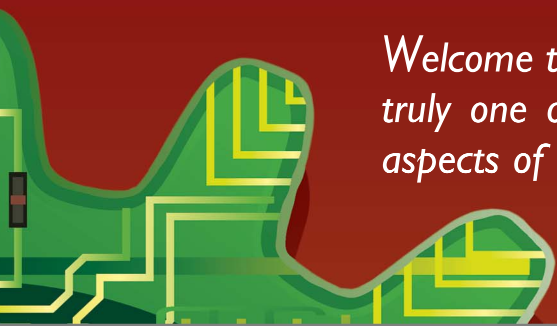
THE PID CONTROLLER

Part 1

Welcome to the world of control systems. This is truly one of the most exciting and fascinating aspects of electronics.

by Aaron Dahlen



In this series of articles, we will explore how to implement both analog and digital control systems. We will be using a PID (Proportional Integral Derivative) controller. With a PID controller, we can control thermal, electrical, chemical, and mechanical processes. The PID controller is found at the heart of many industrial control systems.

In this first of three installments, we will answer the "why" questions. We will also lay a foundation to better understand what a PID controller is. In subsequent installments, we will explore how to tune the PID controller and how to implement a digital PID using the ZILOG Encore! microprocessor.

The goal of this series is to introduce you to the world of control electronics. Concepts will be explained in a simple, intuitive fashion and useful, practical examples will be presented. The math will be kept to an absolute minimum. This is not to say that the math is not important. Quite the opposite — control systems may be modeled and analyzed mathematically. The mathematics is nothing short of amazing and I would encourage you to peruse it. There are hundreds of books that explain the theory and mathematics of control systems. These books will introduce you to powerful tools, such as Laplace transforms, root locus, and Bode plots. Again, this series of articles hardly scratches the surface. There is much more to be learned.

What Is PID Control?

The term PID is an acronym that stands for Proportional Integral Derivative. A PID controller is part of a feedback system. A PID system uses Proportional, Integral, and Derivative drive elements to control a process. Some of you already know what P, I, and D stand for. Don't worry if you don't; we will soon cover these terms with easy-to-understand examples.

Why Do I Need PID Control?

You need the PID because there are some things that are difficult to control using standard methods. Let me illustrate with an example. My first experience with control systems was a failure. My goal was to regulate the output of a power supply using a PIC microcontroller. The PIC read the output voltage with an AD converter and adjusted a PWM to regulate the output. The control strategy was very simple: If the voltage was below a set-point, turn on the PWM. If the measured voltage was above the set-point, then turn off the PWM. The PIC power supply almost worked. It did produce the DC output voltage that I wanted. Unfortunately, it also has a significant AC ripple riding on the DC signal.

The control strategy I just described is called on-off or bang-bang control. Many types of systems use this control strategy. Take the furnace in my house as an example. When the temperature is below the set-point, the furnace is on. When the temp is above the set-point, the furnace is off. Just like my power supply, the plot of temperature over time results in a sine wave.

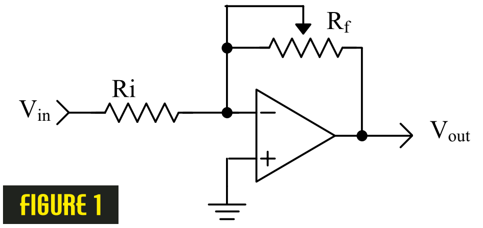


FIGURE 1

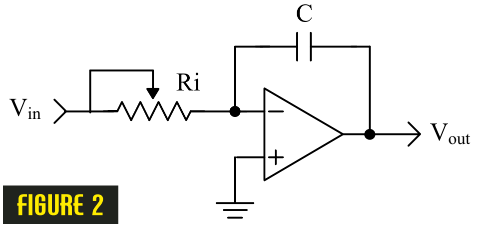


FIGURE 2

For some types of control, this is acceptable; for others, it is not. You wouldn't want this type of control for a servo motor — bad things would happen! Just imagine — the motor would be full power in one direction and, the next moment, full power in the other direction. You can see where the term bang-bang comes from. That servo won't last long!

The PID controller takes control systems to the next level. It can provide a controlled — almost intelligent — drive for systems. We will now examine the individual components of the PID system. This step is necessary to understand the entire PID system. Please don't skip this section; you must know how the individual components function to understand the whole system.

What Is Proportional?

This one is easy. The proportional component is simply gain. We can use an inverting op-amp, as shown in Figure 1. In this op-amp circuit, the gain is set by the values of the resistors. We have the following mathematical relationship:

$V_{out} = -V_{in} * R_f / R_i$

What Is Integral?

Integral is shorthand for integration. You can think of this as accumulation (adding) of a quantity over time. For example, you are now integrating this information into your store of knowledge. Your store of knowledge has components of both time and knowledge. Obviously, we all started as babies with virtually no knowledge. Over time, we have integrated knowledge into our brains.

In our PID controller, we are integrating voltage as time progresses. A schematic of an integrator circuit is shown in Figure 2. The output voltage is described mathematically by the following equation:

Vout = -(1/RC) * (area under curve) + initial charge on capacitor

Area is a component of voltage and time. Let's examine the operation of an ideal integrator. We can simplify the math by making the 1/RC term equal to 1 (i.e., let R=100 KΩ and C=10 µF). Figure 3 illustrates the input/output relationships of the integrator. From Time 0 to 2 seconds, have a 2 V square wave applied to the input of the integrator. The output of the integrator at the end of this time period is -4 V (remember the circuit is inverting). The integrator has accumulated a 2 V signal for 2 seconds. The area is equal to 4. From T2 to T4, there is no voltage applied to the integrator. The output is unchanged. In the remainder of this diagram, you can see that the integrator output changes polarity when the input signal changes polarity.

The previous discussion assumed an ideal integrator. Real capacitors will have some leakage and will tend to discharge themselves. Also, real op-amps may charge the capacitor with no input present. If the circuit is built as drawn, it will likely saturate after a few minutes of operation. To prevent this saturation, add a resistor in parallel to the capacitor. For our purposes, we are not concerned about the saturation. We will be using the integrator with other circuits to control the charge on the capacitor.

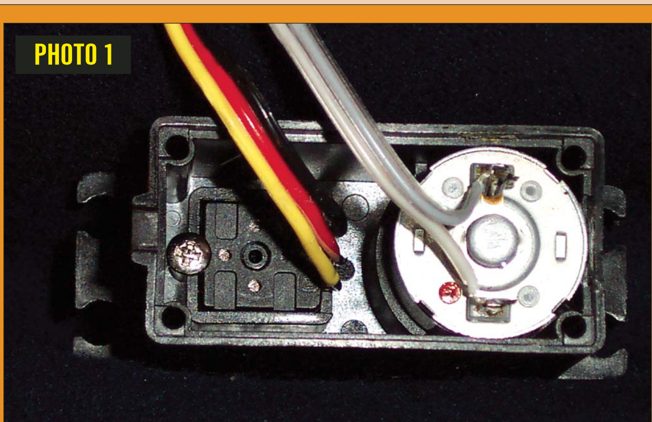


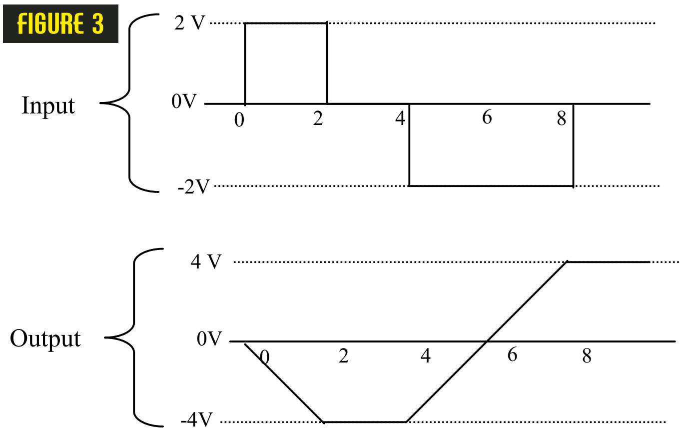
PHOTO 1

PHOTO 2

To better understand the integrator, let's look at a typical application. Integrators are often found in high end audio amplifiers. In this application, they are called DC servos. A typical application is shown in Figure 5. The purpose of this circuit is to remove the unwanted DC voltage from the output of the audio amplifier. Any DC voltage seen on the output of the amplifier will tend to charge the integrator's capacitor. The integrator then changes the bias of the audio amplifier to remove the DC component. The resistor and capacitor are selected so that the circuit will not respond to audio frequencies.

Also, recall that an AC waveform is symmetrical. The part above 0 tends to charge the capacitor, while the part below will discharge the capacitor. Therefore, when you integrate an AC waveform over a large amount of time, you get 0. Even a small DC voltage will charge the capacitor over a long period of time, thus rebiasing the amplifier.

FIGURE 3



What Is Derivative?

The derivative is a measurement of the rate of change. The ideal differentiator is shown in Figure 5. This circuit looks similar to the high pass filters you have seen in other schematics. Low frequencies are attenuated, while high frequencies are allowed to pass. The mathematics that describe the differentiator is:

Vout = -RC * (rate of change)

Rate of change is equivalent to measuring the slope of a line. Slope is a measure of the change in voltage divided by the change in time. In mathematical terms, this is referred to as a delta voltage over delta time or simply dv/dt. If we apply a ramp to the differentiator, we get a steady DC output voltage. Figure 6 illustrates the input/output relationship of

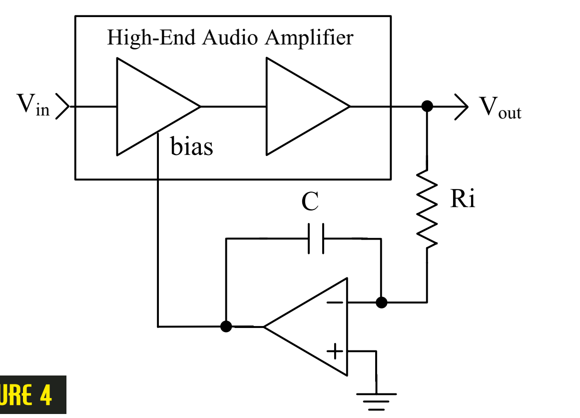


FIGURE 4

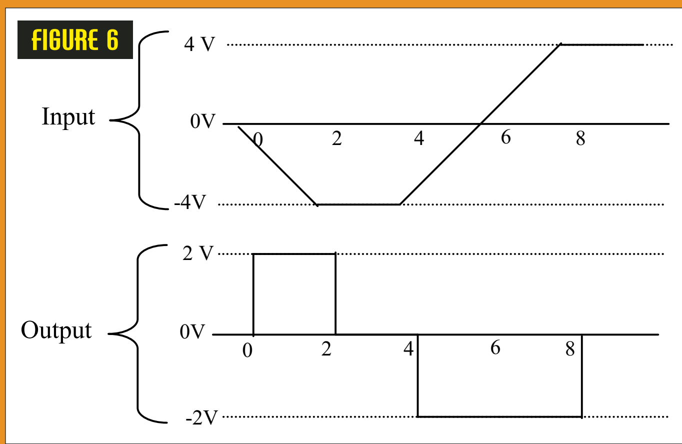


FIGURE 6

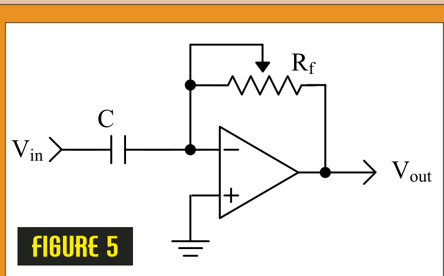


FIGURE 5

a differentiator. To simplify the math, we will let RC=1. From time 0 to 2, the voltage changes -4 volts, while the time changes 2 seconds. The slope of this line is, therefore, -2. The output of the differentiator will be equal to 2 — remember the stage is inverting.

Servo Motor System

Now that we are familiar with the P, I, and D terms, let's examine how they are combined to form a complete system. We will be using the PID controller to control a DC servo motor. I used a Hitec brand servo motor typically found in R/C model cars and airplanes. This servo is inexpensive and readily available. You can also purchase replacement gears — more of that in the next installment!

The servo mechanism consists of several components, as shown in Photo 1. We have a DC motor, a set of gears, and a variable resistor. The resistor is attached to the last gear. This variable resistor is used to determine the rotational position of the motor.

The servo was gutted. I only used the motor and the variable resistor, as shown in Photo 2.

PID Block Diagram

A block diagram showing the functional relationships of the PID controller is shown in Figure 7. The first thing to notice is that this is a parallel process. The P, I, and D terms are calculated independently and then added at the summer ∑. The input to this loop is the set-point — in this application, it can range from −12 to +12 VDC. The output is motor position. Position is measured by the resistor and feedback as a voltage between −12 to 12 VDC. We will now examine each of the PID terms independently to see how they are related. For this discussion, assume that the set-point is 0 VDC.

On the far left of Figure 7, we see a summing junction. The difference between the set-point and feedback is the error of the system. If the measured motor position is positive of where it should be, the error will be negative (i.e., a negative correction is required). Likewise, if the measured motor position is -1, the error will be positive 1 (i.e., a positive correction is required — remember set-point is 0 VDC).

The error is multiplied by the gain of the proportional block. Notice that the block diagram shows this as a negative gain. This was done so that the block diagram and the schematic (presented later) will be consistent with each other. The proportional amplifier output is sent to the second summing junction, where the sign is again inverted. The amplifier boots the signal's current and drives the motor.

This chain gets to be quite long, so let's summarize proportional operation in a few simple sentences:

1. An error must be present!

2. The system will try to correct the error by turning the motor in a direction that opposes the error.

3. The intensity of the correction is determined by proportional gain. If there is no error, there is no proportional drive.

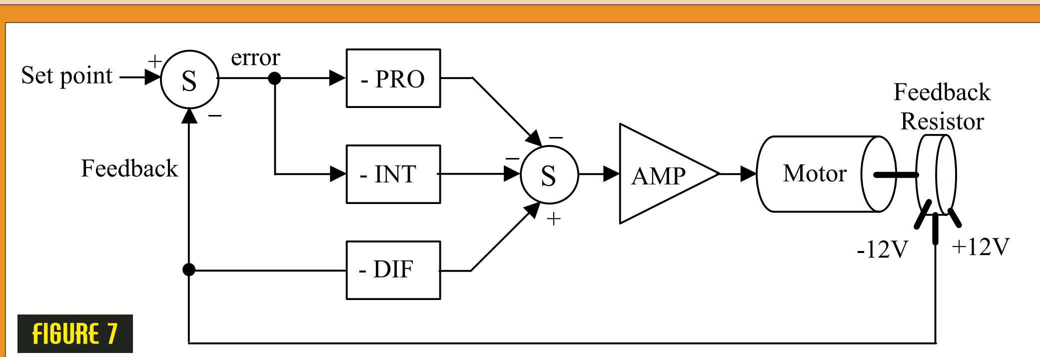


FIGURE 7

Moving on to integral — the integral is a device that charges a capacitor over a period of time. Recall the example of the audio amplifier. In that application, the integrator accumulated the DC output of the amplifier over time. It then rebiased the amplifier to eliminate the DC

error. In the circuit in Figure 7, the integrator is performing the same task. It is integrating the error. It then provides a correction signal to the motor. We can summarize integral action in a few sentences:

1. An error must be present!

2. The integral section accumulates the error. A small error can become a large correction over a period of time.

3. As the error is accumulated, the motor is forced to correct the error.

4. Finally, the integrator will overshoot the set-point. It must produce an error opposite of the original in order to discharge the capacitor.

The final PID component is the derivative. Recall that the output of the differentiator was proportional to the slope of a wave. The same type of action is occurring in this circuit. When the motor starts to turn, the voltage measured by the resistor will be increasing or decreasing. If we have a voltage changing over a period of time, we have a ramp! The slope of this ramp changes with the speed of the motor. If the motor is going fast, the slope is high (i.e., voltage is changing fast for a given amount of time). Consequently, the output of the derivative stage will be high. The differentiator has the following attributes:

1. The motor must be moving!

2. The differentiator will have a high output voltage when the motor is moving fast and a low voltage when the motor is moving slow.

3. This signal is applied in such a way as to slow down the motor.

4. If the motor is not moving, the differentiator has 0 output voltage.

The connections for the differentiator are different than the proportional and integral sections. The differentiator receives its input directly from the resistor. It, therefore, measures only the speed at which the motor is moving. It does not care about the set-point. This is done to prevent large derivative drive signals when the set-point is changed. Again, the differentiator only responds to the speed of the motor.

Schematic

Figure 8 contains a simplified schematic of a servo motor PID control system. This schematic is an adaptation of the PID controller presented by Professor Jacob in his book, *Industrial Control Electronics*. This type of system has the advantage of easy tuning. This circuit is also

simple and easy to construct.

The schematic has the same physical layout as the block diagram. Op-amp U1 is used as the summing junction for the set-point and measured motor position. The individual P, I, and D functions are implemented by U2, U3, and U4, respectively. Finally, op-amp U5 sums the individual PID terms. The P and I terms are inverted, while the D term is not. Darlington transistors have been added to U5 to boost the current to a level sufficient to drive the motor.

The individual P, I, and D components appear just as they were presented earlier in this article. Each of the terms has a variable resistor to adjust its gains. The adjustment (tuning) of this circuit is the topic for the next installment.

Component selection for this circuit is not critical. The variable resistors should be multiturn for ease of adjustment. General-purpose op-amps may be used; however, U3 should be a FET input type. The FET design is better for the integrator, since it will not self-charge the integrator capacitor. I found a quad op-amp — such as the LF347N — to be ideal for this application. Large capacitors are required for the integrator and derivative circuits. The large values necessitate that electrolytic capacitors be used. The electrolytic capacitor may be operated as a non-polarized capacitor by placing two capacitors in series, as shown in the schematic.

A full schematic will appear in next month's installment. You may download the CAD files (in Eagle) from the *Nuts & Volts* website at **www.nutsvolts.com**

Testing

Before we can test the PID circuit, we need to know more about the mechanical system. We need to know how it responds to a command and how the individual P, I, and D terms interact. You will have to be patient and wait for next month's installment. In the meantime, go ahead and breadboard the circuit. You can use a function generator to verify the individual stages. See how the individual stages respond to sine, square, and triangle waveforms. Remember to use a low frequency — less than 10 Hz. This frequency is approximately the same as the servo motor system.

Stay tuned; next month, we will learn how to tune the PID controller. We will add additional circuitry to prevent a condition called integral wind-up. Also, keep a lookout for installment three, where we will implement the PID on a ZILOG Encore! microcontroller. **NV**

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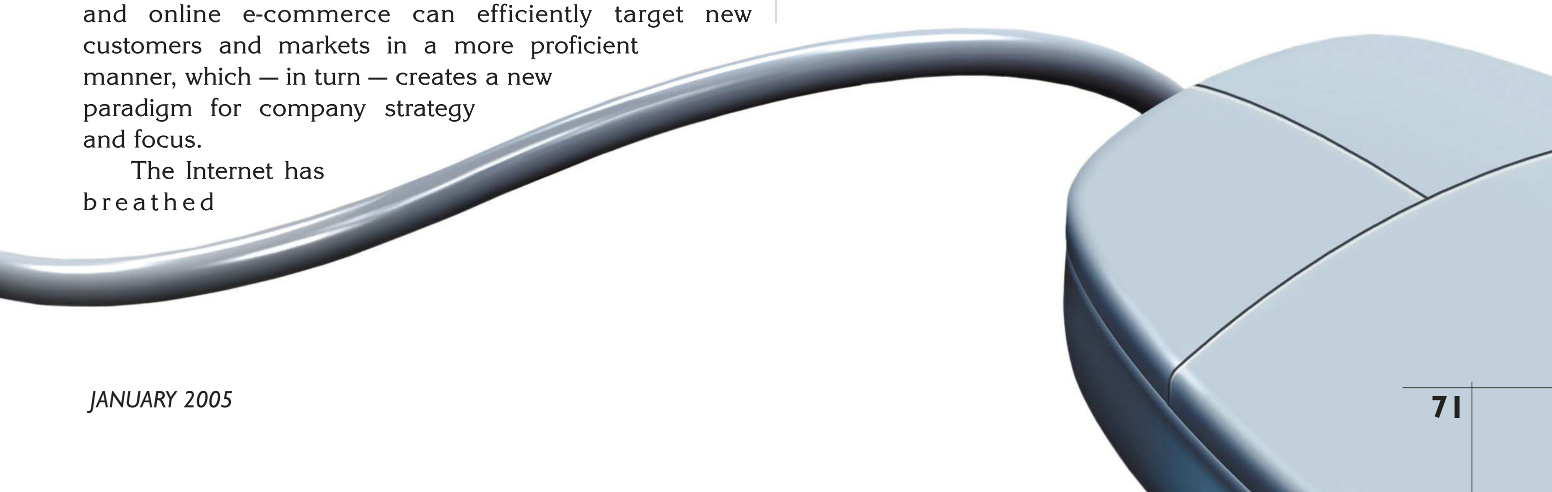
Impact of the Internet on the Printed Circuit Board Industry

by Robert Schnyder

The Internet has transformed business in a very profound way. Similar to the impact of the Industrial Revolution, the Internet has generated tremendous opportunities for growth and expansion. It has created an entirely new way of thinking about the concept of business. Companies that have embraced the Internet and online e-commerce can efficiently target new customers and markets in a more proficient manner, which — in turn — creates a new paradigm for company strategy and focus.

The Internet has breathed new life into traditional business models. For example, "I'll call you," has been replaced by, "I'll Email you." Traditional business calls and company visits have been replaced by Email correspondence or virtual conferencing. Company brochures have been transformed into corporate websites. These changes show the dramatic impact the Internet has made on business today.

One area that has been revolutionized lately is the printed circuit board industry. This article will examine the Internet's impact on the circuit board industry, the transformation of the buying process, and what it means for the



future of circuit board production.

Impact on the Circuit Board Industry

In the field of circuit boards, the Internet has created an explosive proliferation on the traditional concept of the quote and order process. Customization of board specifications has made it difficult to standardize this industry. The evolution of the ordering process demonstrates the Internet's impact based on consumer demand:

Face-to-face => Telephone => Faxing => Email (RFQ) => Online Quoting

All of the above remain important aspects, but online quoting (e-commerce) is the one that has become the most beneficial to consumers. The ability to generate quotes and evaluate parameters online has created a shift in control of the buying process from the supplier to the consumer. It is also important to note that this evolution has also granted consumers more control while reducing the level and time of interaction with suppliers.

E-commerce has forced companies to reinvent traditional business practices and adopt new, consumer-focused strategies to compete online. According to e-commerce research, the most successful online companies provide consumers with all of the following:

- Save the consumer money (or provide the best value).
- Save the consumer time and effort.
- Offer a unique product or service.
- Offer a unique buying experience.

Before the Internet, suppliers did not concentrate on these concepts. They relied heavily on their ability to provide a competitive advantage through a combination of a company's ability to effectively compete on quality, price, and delivery of goods. It was the consumer's responsibility to seek out and obtain quotes from several suppliers, evaluate services, and obtain the best value (which usually meant the best price). Since this was usually a long and tedious process, most consumers remained loyal to a few suppliers to avoid repeating this hassle every time a quote was required.

The Internet has transformed this long-established method for ordering circuit boards — to the benefit of the consumer.

Nowadays, consumers can search the Internet and obtain several quotes from many circuit board manufacturers with minimal contact or interaction with those companies. The time and effort saved through online comparison has provided consumers with a greater flexibility in their choice of suppliers. As a result, companies are reinventing conventional ways to compete for consumer business. Suppliers are not only doing more and making their products more appealing, but are also making the method of ordering those products more convenient.

The Transformation of the Circuit Board Buying Process

Due to the uniqueness and complexity of the circuit board industry, consumers have traditionally relied on interaction with suppliers during the buying process. Even simple circuit boards required that many specifications and factors be taken into consideration. The Internet has leveled the playing field between consumers and suppliers by making the buying process available online (e-commerce).

The buying process has undergone an enormous transformation that has provided both advantages and disadvantages to consumers and suppliers. As suppliers continue to incorporate Internet strategies into their business models, consumers will benefit in a variety of ways. For example, the ability for consumers to generate online, instant quotes provides the following advantages:

- Significant time reduction of the quote process.
- Ability to change requirements and evaluate their effects in real time.
- Eliminates back and forth hassle of traditional quoting.
- Time, involvement, and interaction is decided by customer.
- Levels the playing field for consumers.

Suppliers also benefit from developing an online presence. The Internet provides an entirely new business medium from which companies can develop larger and varied markets, as well as attract new and unrealized customers. It makes the company more accessible and provides a means to address focused messages to target consumers. The Internet provides accessibility 24 hours a day, seven days a week to consumers — both domestic and international. The potential for growth is limitless, which should be very appealing to smaller or specialized

Online Custom PCB Vendors

EPic Design Company — **www.epicdesignco.com**
ExpressPCB — **www.expresspcb.com**
Micromint — **www.micromint.com**
PCB123 — **www.pcb123.com**
PCBexpress — **www.pcbexpress.com**
Pulsar, Inc. — **http://home.flash.net/~yogii**
R4Systems — **www.labceneter-electronics.com**
V & V Machinery and Equipment — **www.vandvmachy.com**

suppliers. The following analogy puts these ideas into perspective:

The Internet is like a new interstate highway, where traffic passes by on a continual basis. The goal for companies is to make that flowing traffic stop and buy. Websites and Internet strategies provide the roadside storefronts and exit ramps from which these goals can be achieved.

What Does This Mean for the Future of Circuit Board Production?

Circuit board suppliers will continually streamline processes to drive down costs. Suppliers should hone in on the manufacturing capabilities they do best and streamline those processes. This will continue to drive down prices, while maintaining quality levels.

The Internet provides a level playing field for smaller board shops to compete with larger ones. Smaller board shops will focus on more concentrated product offerings, based on limited manufacturing capabilities. As more circuit board suppliers — both large and small — adopt online strategies, distinct product offering and categories will begin to emerge.

Consumers will have a greater variety of choice and options. As a result, consumers may not remain loyal as comparison shopping becomes much easier. Consumers will be able to first sort through what services they need and then compare between suppliers who offer the specific services or specifications required.

Finally, will this online evolution bring about the elimination of traditional face-to-face customer service? Not at all, since there will always be consumers who prefer human interaction. Offline interaction will decrease, but it will evolve into more of a complimentary method for ordering when problems and questions arise that cannot be accommodated through the online buying process.

However, consumers will continue to increase their use of online purchasing as long as the buying experience remains beneficial, providing lower cost products and processes while remaining easier, faster, and hassle-free. **NV**

About the Author

Robert Schnyder is the Marketing Manager for he Circuit Board Division of ECD, Inc. He can be reached at robert.schnyder@ecd.com For circuit board designs, the company offers three options to consumers: PCBexpress.com provides low cost, prototype pricing with set parameters and product features. PCBpro.com was created to provide more flexibility by allowing consumers to generate online quotes based on a variety of options and purchase boards online. PCB123.com is free design software that provides schematic and layout design functionality.

King's Bishop to RF

When life-long hobbyist Tom Van Baak's son displayed an interest in chess instead of circuitry, hacking, or programming, they found an interesting way to combine their interests. Tom — a software engineer by profession and an ultra-precise time hobbyist on the weekends — extended his building to a unique chess set.

Like all diligent hobbyists, he has an extensive collection of assorted finds from eBay and the *Nuts & Volts* Classifieds section. Over the years, his accumulation of RF connections grew large enough that he was able to construct this complete set of chess pieces for his son. The pieces — which are gold and silver plated, respectively — are combinations of BNC, SMA, N, APC7, F, and UHF connectors and various elbows. The pawns are 50 Ω terminators. Tom's detail extended to the kings and queens, which are gender-accurate; male and female SMA connectors are mated with larger N connectors to make those pieces.

The set might be a bit removed from his interests in atomic clocks, WWVB, GPS, picoseconds, and the like, but Tom and his son have a beautiful piece of electronics-inspired art to use when they while away those father-son times!

Learn more about this project, along with Tom's elaborate atomic clock museum and home timing lab, at **www.LeapSecond.com** or reach Tom via Email at tvb@LeapSecond.com

Da Vinci Decoding

A Dartmouth College team has developed a set of software tools that can determine the true artist of a painting, print, or drawing. As many pieces of art were done on a "class project" basis, the artist attributed to a work often only painted a portion of the image, with students filling in secondary forms, backgrounds, and details. Additionally, many famous works of art have had their creators questioned for decades or more.

The software analyzes various attributes of the artist's brush or pen stroke and statistically analyzes them and any inconsistencies in a work to validate or refute the authenticity of the piece. Although this may seem far-fetched, the practice is well-established in other fields, such as signature authentication.

"We've been able to mathematically capture certain subtle characteristics of an artist's work that are not necessarily visible to the human eye. We expect this technique — in collaboration with existing physical authentication — to play an important role in the field of art authentication.

"What's remarkable is not only that the mathematics confirms the expert opinion, but that — conversely — the true connoisseur is able to see similarities in detail in the body of an artist's works that is extracted by relatively sophisticated techniques," said Daniel Rockmore, Professor of Mathematics and Computer Science.

The software, which requires an enormous negative — 8" x 10", to be exact — that must be digitized at 16,852 x 18,204 pixels, has already supported the long-held belief that Perugino's "Madonna With Child," which resides in Dartmouth's own Hood Museum, is not entirely the artist's work, but includes the efforts of at least four other painters. In addition, of 13 Bruegel drawings from the Metropolitan Museum of Art in New York City, only eight were determined to be authentic.

Putting the Spotlight on BASIC Stamp Projects, Hints, and Tips

Stamp Applications

Timing Is Everything

The dreaded "I" word ... yes, everybody talks about it ... there's lots of bloviating about it ... but what can we actually do with interrupts? Well, quite a lot, actually — if we're patient and work carefully. Thankfully, SX/B makes interrupt programming more manageable than we thought it could be.

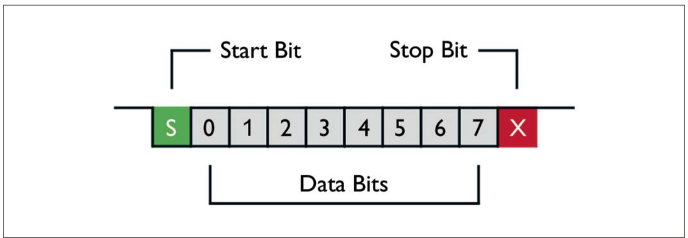
It wasn't very long after the BASIC Stamp and other BASIC language microcontrollers appeared that advanced users started asking about using interrupts. Well, neither the BASIC Stamp family nor — to my knowledge — any of the micros in the same class supports true interrupts; it's just not practical in Basic and I'm about to explain why. Please, please, please ... don't fill my Email basket with flame mail telling me that your favorite Basic language controller does do interrupts; let me qualify my statement.

Let's back up a bit for those who may be a bit new. An interrupt is just that: an event or condition that suspends (interrupts) a program, forces the code into a special section (usually called an ISR, for Interrupt Service Routine), then goes back to what it was doing when the interrupt occurred. Sounds pretty simple and straightforward, right? Well, not quite.

Here's why the BASIC Stamp and similar microcontrollers don't support true interrupts (as I just described): What happens if we're doing a bit-bang serial input (as most micros in the BASIC Stamp class do) and we get an interrupt? Well, if we process the interrupt, our serial timing is going to get trashed and we will corrupt the data — this could lead to a very big problem. The same problem holds true for any time-oriented function — things like **SERIN**, **SEROUT**, **PULSIN**, **PULSOUT**, **PAUSE**, **OWIN**, **OWOUT**, etc. You get the idea.

How is this handled, then? Well, the BS2p family has the ability to do what is called "pin polling." When enabled, the BASIC Stamp 2p will check pin states in between high level instructions and act in accordance with the polling set up configuration (there are several options). This pseudo-interrupt process can be very useful. Now, I realize that some Basic language microcontrollers use hardware UARTs and timers and this does help alleviate the interrupt issue I just described. That said, the use of internal hardware occasionally limits design flexibility as specific I/O points on the micro are required. I'm not saying that any of this is bad ... it just is.

Figure 1. Serial data byte structure.



Give Me an "I"

Okay, now that you know why the BASIC Stamp doesn't support true interrupts, what about SX/B? For those of you who have checked it out, you've no doubt seen that there is indeed interrupt support. Yes, I'm going to show you how to use one type of interrupt this month — and to do two things with it: receive and buffer serial data (coming from a BASIC Stamp host) and to multiplex an eight-digit, seven-segment LED display.

The warnings I gave about interrupts above apply to SX/B — the difference is that SX/B allows interrupts any time you configure them. So, if you're going to be using interrupts in an SX/B program, you should not be using any of the time oriented functions I mentioned earlier (note that SX/B does not have the one-wire commands of the BS2p).

As this is going to be a bit of a ride, let's get right to it. I was in my favorite store the other day (yes, Tanner Electronics in Dallas, TX) and found a surplus eight-digit, seven-segment LED display that cost $1.00; that's

right, $1.00. How could I not buy it? The question now was control. It's a common-cathode display, which means that the segment anodes for all eight digits are tied together. The only way to use such a display properly is with a multiplexing controller. Of course, I could use a MAX7219, but they're not cheap or easy to find anymore. Why not roll up my sleeves and create my own controller?

The idea was to create a serial LED controller that is AppMod protocol compatible — which means it could be controlled from one BASIC Stamp pin and can even share that pin with the line follower we created last month. While this seems to be a simple task on the surface, it does present a serious challenge.

To use the display properly, each active digit has to be refreshed at a regular rate. If we weren't doing anything else and the display was static, we could handle this in a program loop — especially in a compiled language like SX/B. The "problem" is that we want to be able to receive and buffer serial data at the same time. What this means for us, then, is that we will create an interrupt-driven program that multiplexes the display and handles the serial input.

Bit-Bang Serial Interrupt Style

Take a look at Figure 1; this shows the structure of a serial byte in True (input idle state is high) mode. The stream begins with a start bit; this actually lets the receiver sync up and get ready for the incoming data bits, which will arrive LSB to MSB. At the end of the stream is a Stop bit period. Under non-interrupt conditions, the processor will simply loop until the serial line goes low to indicate a start bit. A timer is set for 1.5 bit periods so that the first bit is sampled in the middle of its period. After that, the timer is reloaded with the bit period and the rest of the sampling happens in a loop. If you want to see this for yourself, use **SERIN** in an SX/B program and look at the assembly code that gets generated.

In our project, however, we can't sit around waiting for the bit to come in, as we have to update the display periodically. What we have to do is sample the serial line at a rate that will let us accurately capture the incoming data. So, how fast do we sample? Well, I actually checked with programmers who are much better at this stuff than I am and the consensus was that — when doing interrupt-driver serial input — one should sample the serial line at least four times per bit period.

Okay, decision time. In order to know how fast to sample the serial line, we need to know what baud rate we want to support. For this project, I decided to go with 9600 baud, as this is somewhat standard for serial accessories and is supported by most micros. Also, if we can sample at 9600 baud, then lower baud rates will be no problem; they'll simply have longer bit timing periods.

At 9600 baud, the bit period is 104 microseconds (1/9600). If we want to sample four times per bit period, we have to do that every 26 microseconds. So, that's our first hurdle: set the interrupt so that it activates every 26 microseconds.

To do this, we're going program the SX to create a periodic interrupt based on an internal value called the RTCC (Real Time Clock/Counter). This eight-bit value can be incremented by a change of state on an external pin or by the oscillator that runs the SX. Since we can have a range of speeds to run the SX, we also have the ability to divide the oscillator frequency before sending it to the RTCC. This is called the prescaler and usually comes into play when we're running the SX at very high speeds (e.g., 50 MHz).

For this project, we'll run at 4 MHz, so the prescaler won't be required. What we'll have to do is set up the OPTION register in the SX to enable RTCC updates on the internal clock without being divided by the prescaler. Here's how:

```
OPTION = %10001000
```

This configuration allows RAM address $00 to access the RTCC (bit 7=1) enable interrupt when the RTCC rolls over to zero (bit 6=0), increment RTCC on internal

instruction cycle (bit 5=0), and set the divide rate for the RTCC to 1:1 (bit 3=1). The SX28 documentation (download from Ubicom — **www.ubicom.com**) goes into all the details of the OPTION register.

Okay, now that we've enabled interrupts, how do we make that happen at the desired interval of 26 microseconds? Here's what an empty ISR block looks like in SX/B:

```
INTERRUPT

  ' ISR code

RETURNINT 104
```

The key is actually at the end — the value following **RETURNINT**. This tells the SX how many cycles to run before generating an interrupt. How then, did we come up with 104? We start with the clock frequency of our project: 4 MHz.

At this rate, each instruction cycle takes 0.25 microseconds. Since we want our interrupt to trigger every 26 microseconds, we divide the instruction cycle speed into that. So, 26 divided by 0.25 is 104. This works because it is less than 255 (the maximum value of the RTCC). If you're ever doing a project where your interrupt cycles calculate to greater than 255, you either have to reduce the oscillator speed or enable the RTCC prescaler.

At this point, our program will be interrupted every 26 microseconds — a rate that we've determined is fast enough to sample the serial input line enough to accurately capture data at 9600 baud Okay, let's do it.

```
ISR_Start:
  ASM
    BANK $00
    MOVB C, Sin
    TEST rxCount
    JNZ RX_Bit
    MOV W, #9
    SC
    MOV rxCount, W
    MOV rxTimer, #BitTm15

RX_Bit:
    DJNZ rxTimer, Multiplex
    MOV rxTimer, #BitTm
    DEC rxCount
    SZ
    RR rxByte
    SZ
    JMP Multiplex

RX_Buffer:
    MOV FSR, #rxBuf
    ADD FSR, rxHead
    MOV IND, rxByte
    BANK $00
    INC rxHead
    CLRB rxHead.4
  ENDASM
```

Even though SX/B allows high level code in the ISR, we're not going to do that for the serial input. Why not? Well, there are two reasons: With assembly language, we can be a tiny bit more code-efficient and — even more importantly — the code was already written and working, so why not just use it?

Let me pause for a second and suggest that, if you're serious about programming the SX, you should consider the books that Parallax makes available: *Exploring the SX Microcontroller* by Al Williams (no, we're not related, but he lives in TX, too) and *Programming the SX Microcontroller* by Guenther Daubach. Both authors are great guys and very active in the Parallax support forums. You can get an SX starter kit that includes both books and — if you're on a budget — Al's book is available as a free PDF download.

Okay, back to the code. On entering the ISR, we want to make sure that we're pointing at the serial variables, so we issue a BANK $00 statement to do that. Then, we sample the serial line by copying it into the SX Carry bit. When the serial line is idle, the Carry bit will now hold a value of 1. Let's continue to go through the code as if we're in the idle state. The TEST instruction will set the Zero bit if the register tested holds a value of zero. In our program, the variable rxCount is used to count down the

bits as they're coming in; when rxCount is zero, we are not currently receiving a byte.

The next instruction, JNZ, will force the program to jump to RX_Bit when the Z flag is not set — this happens when we are receiving (rxCount > 0). Since the Z flag is currently set, we will fall through the JNZ to where we load the value of 9 (start bit plus eight data bits) into the W register. After that, we will check the Carry bit; if it is 1 (and it currently is), we will skip the loading of rxCount and load the bit timer (rxTimer). With rxTimer loaded, we drop into RX_Bit, where the timer is decremented and — if not 0 — the serial routine jumps to the label called Multiplex.

This process will repeat every interrupt cycle until a start bit is received. You may be wondering — as I did — why the rxTimer gets loaded when there is no start bit. Well, the reason there is no bail-out on a no start bit condition is that it actually adds more code than simply allowing the rxTimer to be loaded and the routine to exit.

Now, a start bit arrives; let's see what happens. This time, through, we will move 0 into the Carry bit. As rxCount is still 0, we will not jump to RX_Bit, but we will end up moving 9 into rxCount (via W). Now, we load the rxTimer with 1.5 bit periods, decrement the timer for this interrupt cycle, and exit. On the next interrupt, we will have 9 in rxCount, so the code will jump right to RX_Bit after sampling the serial line and then the rxTimer will be decremented again. This will continue until rxTimer is 0.

At this point, we're actually in the middle of the first data bit (the LSB). We will reload the rxTimer with the bit timing and then decrement the rxCount to account for the start bit. The program will drop through the SZ (skip, if zero) instruction, since rxCount is at eight and then move the data bit (currently sitting in Carry) into rxByte with the RR (rotate right) instruction.

Finally, the program will drop through another SZ instruction and jump out of the serial routine to the Multiplexer.

This process will continue for eight bits. After the final bit arrives, rxCount will be 0 and the code will end up skipping the JMP Multiplex instruction and move to RX_Buffer. This code will save the incoming byte to a 16-byte circular buffer. This will let our foreground program handle important business while bytes are streaming in. That said, it's a circular buffer and — if we don't pull data from it before it fills — it can end up overwriting itself. That won't be a problem with our display.

The code at RX_Buffer uses indirect addressing via the FSR (File Select Register) to update the circular

buffer. We start by moving the location of the first byte of the buffer into the FSR, then adding the head pointer (rxHead) to that. The MOV IND instruction takes the value of rxByte and puts it into the location being pointed to by the FSR. Then, we update the position of the head pointer and make sure that it stays within a 0 to 15 range by clearing bit 4. At the end of our serial section, we can terminate the assembly code block of our ISR with the **ENDASM** instruction.

Did you just take a big breath? I did! There will come a point when this all seems trivial, but — until you get to that point — you might want to review it a few times. It wouldn't hurt to map the position of the counters and bits on paper so that you make sure you understand it. By understanding how this works, you'll be able to modify it to suit your needs for a different application.

Taking the Mystery Out of Multiplexing

Remember that our project has another important task: we have to multiplex the LED display, which means selecting the active column (cathode) and then activating the appropriate segments (anodes) to create the desired pattern. We will handle this "in the background" via the ISR. This is actually much easier than the serial code though and can be done with SX/B instructions.

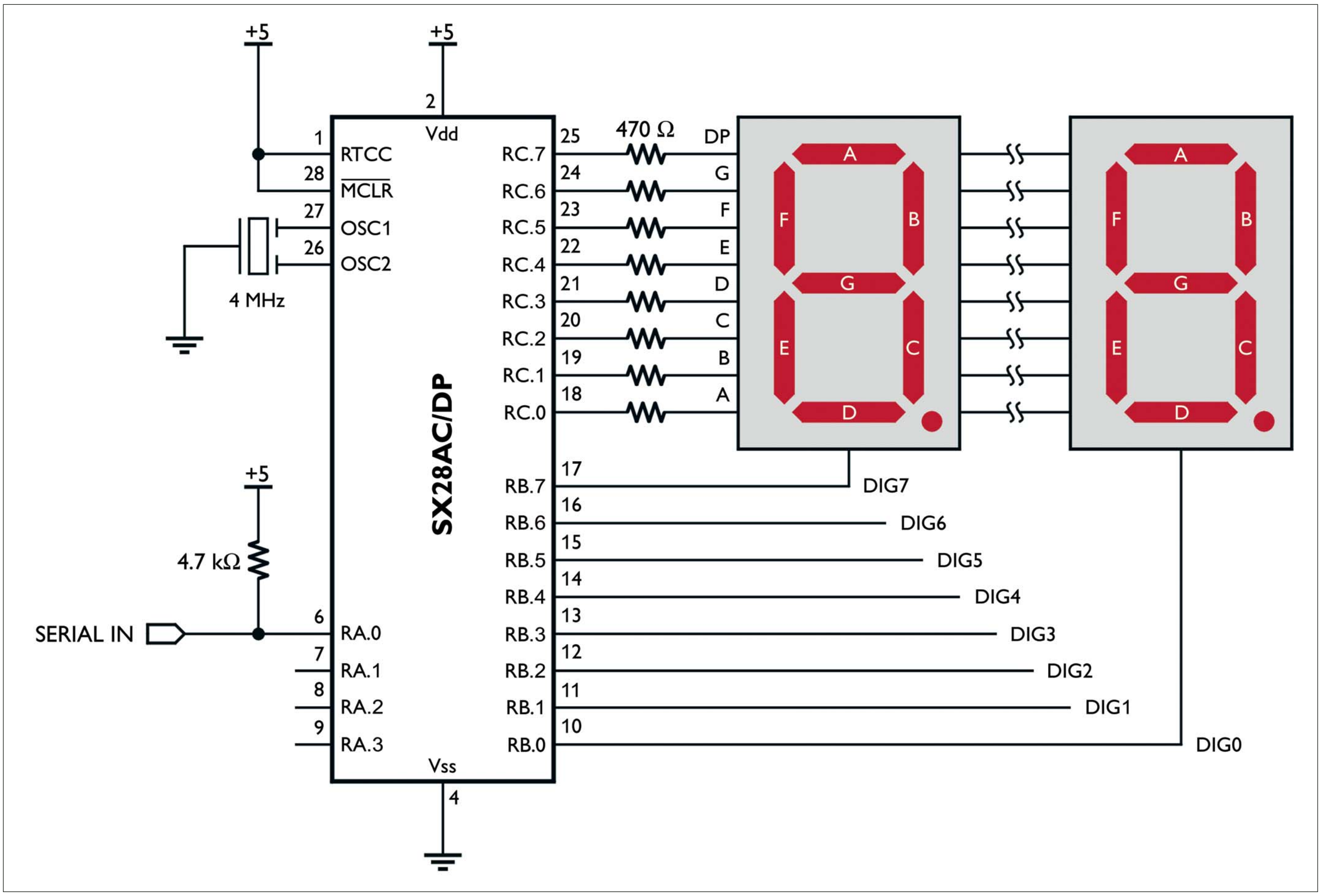
```
Multiplex:
  INC digPntr
  IF digPntr <= 7 THEN Next_Digit
  digPntr = 0

Next_Digit:
  Cathodes = NoDig
  IF digPntr > limit THEN ISR_Exit
  Anodes = anoBuf(digPntr)
  IF digBlank = 1 THEN ISR_Exit
  READ DigCtrl + digPntr, Cathodes

ISR_Exit:
  RETURNINT 104
```

The first step is to increment the variable called digPntr that points at the current active column. The next line will compare the value of digPntr to 7 (last legal column value) and, if digPntr is less than or equal to 7, then we will move on to Next_Digit. Once digPntr hits 8,

Figure 2. SS8 schematic.



we will reset it before moving on. If you modify the program for a smaller display, be sure to update this section of code.

The code at Next_Digit actually updates the display. We start by turning it off — this will prevent ghosting when we change the anode (segments) values. Next, we're going to check a couple of values that can be set by the user via serial commands (more on that later). The first is the blanking bit, which turns the display off without affecting the contents of the display buffer. When blanking is enabled, we jump right out of the ISR before enabling the current column. The next value checked is the column limit. This lets us decide how many columns to activate (starting from the rightmost position). If the column pointer is beyond the column limit, we jump out of the ISR before activating the current column.

Finally, when blanking is off and the current column is active, we will move the contents of the anodes buffer for that column to the display. Then, we activate the column by setting its cathode control line to 0 and we're done.

Take another breath. The really cool thing about all this is that the multiplexing code was written in Basic — SX/B Basic. That's really neat. Now, before you get too excited, there is something very important to keep in mind: You must keep the longest path through the ISR to less than the number of cycles assigned to the ISR activation, minus three cycles (101, for this project). If we go over, what will happen is that an interrupt cycle may get ignored if it occurs while the current interrupt is still running (the SX disables interrupt while running the ISR) and this could be catastrophic for programs that require specific interrupt timing.

You can check the length of the ISR by looking at the assembly output — using Ctrl-L in the SX-Key editor is a quick way to do this. In this program, the final address of the ISR is $0056 (86), so we're in good shape.

Back to Easy Street

With the interrupt routine coded and working, the rest of the program is downright simple. Let's go through the important parts. In the beginning, we want to wait for the proper header string before processing any commands — this keeps us AppMod-compatible. The header for the LED controller is "!SS8" and will be followed by a command and one or more data bytes.

```
Main:
  GOSUB Get_Byte, @cmd
  IF cmd <> "!" THEN Main
  GOSUB Get_Byte, @cmd
  IF cmd <> "S" THEN Main
  GOSUB Get_Byte, @cmd
  IF cmd <> "S" THEN Main
  GOSUB Get_Byte, @cmd
  IF cmd <> "8" THEN Main
```

This code looks very similar to what we did in the line follower program. It simply goes through the input until the sequence "!SSR" is received. Remember that our serial input is being placed into a circular buffer by the ISR, so we need to write a routine to retrieve the first available byte.

```
_Get_Byte:
  IF rxTail = rxHead THEN _Get_Byte
  regAddr = __PARAM1
  temp1 = rxBuf(rxTail)
  INC rxTail
  rxTail = rxTail & $0F
  __RAM(regAddr) = temp1
  RETURN
```

Just as we did last time, we can pass the desired variable address by using the "@" preface. In the Get_Byte routine, this causes the address of that byte to be saved. Then the routine compares the value of the tail pointer (where we will get the byte) to the head pointer (where the next incoming byte will be saved). If these values are equal, the buffer is empty and we'll loop to the top of the routine until something arrives.

When the buffer isn't empty, we will move the byte currently sitting in the tail position to a temporary variable. As we did with the head pointer in the ISR, we have to update the position of the tail pointer and force it to stay within the 0 to 15 range of valid buffer addresses. Finally, we move the serial byte (sitting in temp1) to the variable specified by the caller by using the system __RAM() address. This is new in SX/B version 1.1 and makes it easy to modify or retrieve any SX RAM address.

Once we have the header, we will grab the command byte and then jump to a routine that takes care of any data or processing required by the command.

```
Get_Cmd:
  GOSUB Get_Byte, @cmd
  IF cmd = "R" THEN Do_Reset
  IF cmd = "C" THEN Do_Config
  IF cmd = "X" THEN Do_Blanking
  IF cmd = "W" THEN Do_Write
  IF cmd = "B" THEN Do_Block
  IF cmd = "<" THEN Do_ShiftL
  IF cmd = ">" THEN Do_ShiftR
  GOTO Main
```

To some, this structure may look a bit clunky, but keep in mind that SX/B is designed to be very close to assembly language. This lets the code compile very cleanly and, more importantly, it lets us learn from the compiled code. In many instances, you'll see that there is a one-to-one relationship between SX/B instructions and SX instructions. SX/B is built for speed.

Let's have a look at the valid instructions, starting with "R" for reset. The purpose of this command is to clear the serial buffer, clear the display buffer, and set the display mode for each column.

```
Do_Reset:
  GOSUB Get_Byte, @colMode
  rxHead = 0
  rxTail = 0
  limit = 0
  colEnable = %11111111
  FOR idx = 0 TO 7
    digBuf(idx) = 0
  NEXT
  GOSUB Update_Anodes
  GOTO Main
```

Note that the reset command allows us to specify the column mode bits. Since our display is eight digits wide, a single byte works perfectly. A "0" bit (default) indicates that the column is decoded — that is, the value in the data buffer will be translated to the appropriate patterns for the values 0 to F (15). A "1" bit in the mode byte will cause the raw bit's value to be transferred to the display. This feature allows us to define other alpha characters and special patterns that may be used in animations (the BS2 demo program shows off this feature).

The rest of the reset code clears the serial input buffer, sets the display limit to one column, enables all columns (up to the column limit), and clears the display buffer (digBuf). After these changes are made, we have to call the Update_Anodes subroutine as the anodes buffer is what gets transferred to the display in the ISR.

```
_Update_Anodes:
  FOR temp1 = 0 TO 7
    temp2 = 0
    temp3 = colEnable >> temp1
    IF temp3.0 = 0 THEN _Put_Dig
    temp2 = digBuf(temp1)
    temp3 = colMode >> temp1
    IF temp3.0 = 1 THEN _Put_Dig

_Decode_Dig:
    temp2 = temp2 & $0F
    READ SegMaps + temp2, temp2

_Put_Dig:
    anoBuf(temp1) = temp2
  NEXT
  RETURN
```

This subroutine probably looks a bit more complicated than it is. The code loops through eight columns, first checking to see if a column is enabled. If it isn't, the anodes buffer for that column is cleared. If the column is enabled, then we need to check the mode for that column. When the mode bit is "0," we will take the low nibble of the column value and use it as an index into the patterns table that make up the shapes for the numbers 0 through F. If the mode bit for a column is "1," the raw value is transferred to the anodes buffer. After the display is reset, we may want to change the configuration. Let's say that we wanted to enable the rightmost three columns in decoded mode. Here's how we could do that using a BASIC Stamp:

```
  SEROUT Sout, Baud, ["!SS8C", 2, 0, $FF]
```

The first byte in the stream limits us to the third column (column 2). The next byte specifies that all columns are decoded (all bits are 0) and that all visible columns are enabled. Let's look at the code that processes the "C" (configuration) command:

```
Do_Config:
  GOSUB Get_Byte, @limit
  GOSUB Get_Byte, @colMode
  GOSUB Get_Byte, @colEnable
  limit = limit MAX 7
  GOSUB Update_Anodes
  GOTO Main
```

As you can see, there is no magic here — we simply grab the bytes coming in and move them to their respective variables. The only byte of concern is the column limit, which has a maximum value of 7. The **MAX** operator handles this for us. Since the configuration command can change column display modes and enable bits, we need to call Update_Anodes again to refresh the anodes buffer.

Before we run out of space, let's actually put a value into the display, shall we? We're going to use the "W" (write) command that will let us specify a column and a value to write to it.

```
Do_Write:
  GOSUB Get_Byte, @idx
  GOSUB Get_Byte, @cmd
  IF idx > 7 THEN Main
  digBuf(idx) = cmd
  GOSUB Update_Anodes
  GOTO Main
```

After retrieving the column and data values, we just need to make sure that a column value beyond our display has not been specified. If this happens, we exit to Main and leave the raw digits buffer alone. If the column index is good, then we update the digits buffer and — as we did before — we update the anodes buffer, as well. This updates the display. Before we go, let's look at a bit of PBasic code that can run the project — it will make sense of some of the main features.

```
  idx2 = 0
  FOR cntr = 1 TO 100
    FOR idx = 0 TO 2
      SEROUT Sout, Baud, ["!SS8W", idx, cntr DIG idx]
    NEXT
    SEROUT Sout, Baud, ["!SS8W", 7, 1 << idx2]
    idx2 = idx2 + 1 // 6
    LOOKDOWN cntr, <[10, 100, 1000], last
    LOOKUP last, [$FE, $FC, $F8], cMode
    LOOKUP last, [$C1, $C3, $C7], cEnable
    SEROUT Sout, Baud, ["!SS8C", 7, cMode, cEnable]
    PAUSE 100
  NEXT
```

The purpose of this code is to display a three-digit counter in the display, as well as run a little animated "bug" on the left. The main loop handles the counter. At the top of the main loop is a smaller inner loop that uses the Write command to send the counter digits to the display.

Notice how convenient the **DIG** operator is for us in this application. The next section animates the outside segments of the leftmost display. It's a very simple attention getter.

Now that we have data in the SS8 buffer, we need to configure the display so that digits are shown on the right and the animated "bug" on the left.

With **LOOKDOWN**, we can determine how many columns the current count value occupies and, with that value, **LOOKUP** will give us the proper column mode and enable bytes. This lets us blank leading zeros and create a more professional looking display.

One of the things that you probably noticed is that the column mode and column enable bytes can — in some cases — be used to accomplish the same thing.

If I'm being honest, the column enable feature was a late addition to the project and this came after a lot of display experimenting. One technique that I experimented with while I was developing the code was prewriting to the display, and then revealing the display column by column by updating the column enable byte.

Well, it's up to you now. I will admit that programming the SX — even with SX/B — can be challenging, however the rewards are really worthwhile.

If you use this display project as a guide, you can build any number of serial accessories that require buffered input. But be sure to download the SX documentation for the Ubicom, and please do check out the books I told you about; they will really make your journey into SX mastery far easier.

By the way, please feel free to contact me at the email address provided. I look forward to hearing from *Nuts & Volts* readers!

Have a Happy New Year! And until next time ... Happy Stamping. **NV**

Resources

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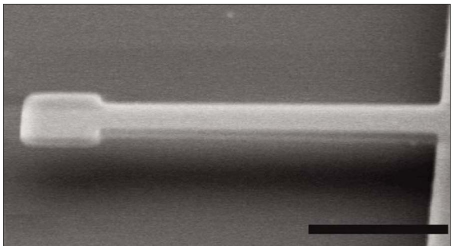
TechKnowledgey 2005

Events, Advances, and News From the Electronics World

Advanced Technologies

Oscillator Senses Viruses



Scanning electron micrograph of a cantilever oscillator 6 µm long, 0.5 µm wide, and 150 nm thick, with a 1 µm square paddle. The scale bar corresponds to 2 µm. Courtesy of Craighead Group, Copyright Cornell University.

Suppose you want to measure an extremely small entity, such as a bacterium, a virus, or the amount of weight you have lost by taking Cortislim®. A standard scale just won't do the job; you'll need an exotic device that is capable of detecting extremely low mass. No problem there, though, if you have access to a cantilever oscillator developed at Cornell University (**www.cornell.edu**).

The principle is pretty simple. Think of a kitchen knife that you just tossed across the room, sticking it into the front door. It will quiver on its own for a short time, using energy left over from the throw. After that, if you make the door vibrate at the knife's resonant frequency, the knife will respond with the same lateral oscillation.

The knife's resonant frequency depends partially on the mass of the handle, so — if you stick a piece of gum on it — the resonant frequency will change. Obviously, it would be possible to compute the mass of the gum if you have a basic knowledge of how a change in mass affects the resonant frequency.

To enable such measurements on a nanoscale level, Cornell researchers simply substituted a silicon paddle for the knife and reduced its length to 6 to 10 µm. If you mount the paddle on a piezoelectric crystal instead of your front door, it can be made to vibrate at frequencies of 5 to 10 MHz. By adding a few virus particles to a paddle, you can change its resonant frequency by about 10 kHz, which is easy to detect.

In the reported experiment, researchers were able to sense as few as half a dozen viruses and they believe the device to be inherently sensitive enough (down to about 0.41 attograms) to sense just one. The type of viruses used in the experiment (Autographa californica nuclear polyhedrosis, in case you care) weigh about 1.5 femtograms. One complication is that air has a tendency to damp the paddle's vibration, so measurements must be made in a vacuum, but it is otherwise pretty straightforward.

With development, the technique could provide a practical way to look for other viruses, DNA, proteins, and toxic organic chemicals. In addition, by using arrays of paddles, one could build a simple field detector that tests for a range of pathogens in a single pass.

Speed of Light = 670 MPH

If you want to communicate over long distances using optical fibers, it's usually a good thing that light travels at roughly 186,000 MPS. However, light occasionally needs to be slowed down so signals can be routed, converted, or synchronized. A common way to do that is to feed it into a loop, but it currently takes 300 km of fiber to delay an optical signal for a thousandth of a second, so it would be really helpful if you could slow it down.

It now appears that physicists at the National Institute of Standards and Technology (NIST, **www.nist.gov**) have figured out a way to do that. The key is the optical soliton — a solitary, intense light pulse that can travel long distances without changing its shape or spreading out. The NIST people have shown that it is possible to use a very stable pulsed laser to create a soliton that travels slowly through a cryogenic gas of rubidium atoms for more than 5 cm without noticeable distortion.

Using this principle, the soliton could travel at one millionth of the usual speed of light and the 300 km of optical fiber could be reduced to a few centimeters. The next step for NIST scientists is to translate the theory into practical experiments. The long term goal is to help simplify and reduce the cost of high speed optical communications.

Computers and Networking

"Fastest Computer" Title Changes Hands Again

Last September, IBM's Blue Gene supercomputer became the big

NEC's SX-8 is rated at up to 65 TFLOPS when configured with 512 nodes. Courtesy of NEC Corp.

dog on the block by achieving 36.01 TFLOPS performance, based on the Linpack benchmark.

However, NEC Corporation (**www.nec.com**) has announced the worldwide launch of its model SX-8, claiming that it can deliver 65 TFLOPS.

Using the same vector architecture as NEC's Earth Simulator, the new product combines enhanced CPUs with improved memory and I/O processing performance.

An enhanced, single-chip vector processor — also used by the SX-6 — contributes to the improved price performance and space savings offered by the SX-8. The machine is intended for use in fields that require large scale and ultra high speed computing of massive data, such as meteorological forecasting, environmental simulations, and automotive crash analysis.

The single-node model (which can include up to eight CPUs) will give you only 128 GFLOPS, so you'll need to order a multiple-node to achieve peak performance. Monthly rental charges are reported to start at about $11,000.00.

Keep in mind, however, that the "fastest supercomputer" crown is still being passed around and IBM plans to get it back by delivering a 360 TFLOP machine to the Lawrence Livermore Laboratory later this year.

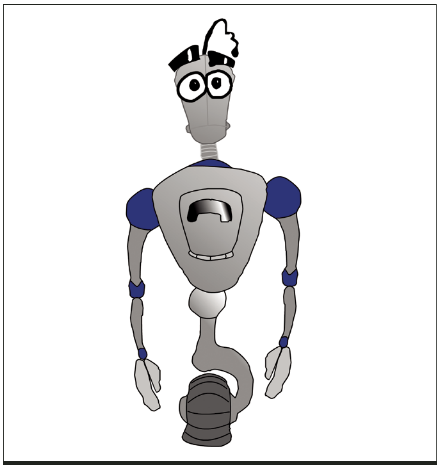
New Portable USB Hard Drives

Western Digital's Passport drives are compact and require no separate power supply. Courtesy of Western Digital Corporation.

Late in 2004, Western Digital Corporation (**www.westerndigital.com**) unveiled the Passport line of portable USB hard drives offering a choice of 40 or 80 GB capacities and (in most cases) no need for a separate power supply. The drives are based on the 2.5 inch Scorpio mechanism, include the company's Data Lifeguard data protection, and are packaged in a rugged case.

According to the vendor, WD Passport Portable Drives are able to withstand the rigors of mobile professionals and other users who need to carry substantial amounts of data with them. A detailed product spec sheet and photos of the drives are available on the company's website. The list price is $199.00 for the 40 GB version and $249.00 for the 80 GB one.

Playing With Disaster



Disaster Dave helps kids learn disaster readiness skills in "Disaster Dave's Misadventures," a new educational computer game developed by Purdue Extension and the Federal Emergency Management Agency.

For those who want to teach children in the community about

disaster readiness (and perhaps scare the bejeebies out of them at the same time), "Disaster Dave's Misadventures" — an educational computer activity — has been developed by Purdue University Extension with funding from the Federal Emergency Management Agency (FEMA).

Now available to the public, its focus is to teach disaster readiness skills in a fun and entertaining fashion with the assistance of "Disaster Dave," whom students help navigate through a variety of natural and other disasters. Faced with blizzards, tornadoes, hazardous materials spills, and national security emergencies, Disaster Dave's fictional community is either destroyed or spared, depending on the skills and knowledge of the player.

In one activity, for example, Disaster Dave faces a snow emergency. He has to decide how and when to take shelter and what items to pack in disaster supply kits. If Dave makes the right choices, the city and its residents make it through the storm.

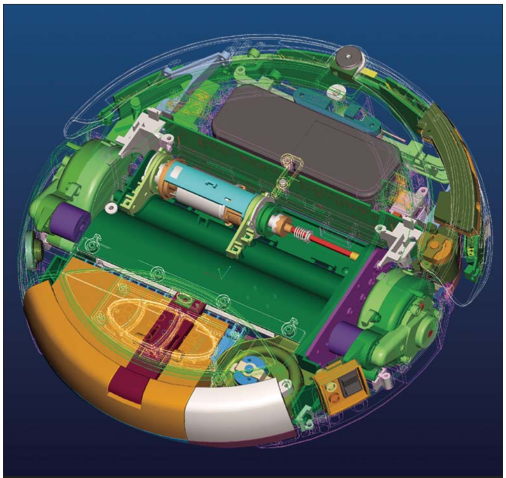
However, if he makes poor choices, the simulated story worsens and the city is trashed (pretty much like Washington, DC, every time it snows). Single copies are available for $10.00 and organizations can buy a set of 25 for $150.00. Details are available at **www2.ces.purdue.edu/eden**

Power Supplies Recalled

If you own a Dell Latitude, Precision, or Inspiron notebook computer and bought it between September 1998 and February 2002, you'll want to take a look at the power supply. About 990,000 of them — manufactured by Delta Electronics — are being recalled because of a risk of fire or electrical shock. The afflicted adapters are marked with part numbers P/N 9364U, P/N 7832D, or P/N 4983D. For more information, visit **www.delladapterprogram.com**

Circuits and Devices

Robot Passes 1 Million Sales Level


This CAD rendering of the Roomba shows that there is much more to this robot than meets the eye. Intricate sensors are required for everything from drop offs, walls, pets, and floor coverings.

Two decades ago, we imagined a future in which intelligent robots would free humanity from dull, dangerous, and repetitious labor, dutifully generating previously unimagined prosperity and freeing us for a pursuit of happiness unencumbered by material needs.

We have fallen a little short of


iRobot wizard Joe Jones discusses the engineering behind the steering and drive mechanisms of the Roomba.

that, but at least many of us have stopped vacuuming our floors. Yes, as of late 2004, more than a million people had purchased the $200.00 Roomba robotic floor vacuum from iRobot (**www.irobot.com**).

Well, maybe having an oversized hockey puck wandering around your house isn't all that romantic, but owners generally report that it actually works. The Roomba has infrared sensors that allow it to follow walls and avoid falling down stairs, wheel-drop sensors that stop the unit when it is lifted, and a bump sensor that keeps it from interfering with furniture and other objects on the floor.

It also employs a flapper-and-brush system to pick up large particulates and a high velocity nozzle that sucks up small particles, such as dust. The latest Discovery and Roomba Red models add a system called Dirt Detect that senses particularly dirty areas and tells the robot to concentrate on them until they are clean.

One reviewer noted that his Roomba (affectionately named "Monica") doesn't do stairs or baseboards, requires frequent emptying, and can leave dirt when moving from tile to carpet.

However, he noted that it provides a cleaner house, with very little effort and at an affordable price. Now, if they can only get it to feed and walk the dog, we would all be set!

Humidity Sensor/Controller Introduced

If your latest design employs sensitivity to moisture or temperature, you may be interested in the HS-2000C humidity sensor/controller from Precon, Inc. (**www.preconusa.com**), which combines analog moisture and temperature sensing with dual channel on/off control capability.

Based on user requirements, high and low limits are embedded in the device at the factory and it can be configured for either direct or reverse action. The two outputs will equal either zero or the supply voltage, which can range from 2 to 5 V. Proportional control, LCD display, and various packaging options are also available. The dime-sized HS-2000C is a little pricey at $35.00, but it is available in small quantities with no programming charge. Accuracy is rated to ±2 percent, with good stability from -30 to +100°C.

Industry and the Profession

Things Sneaking Under Your Hood

For many years, "black boxes" have been used in commercial aircraft to gather and retain crash data. You may not be aware of it, but similar devices are now appearing in noncommercial Earth-bound vehicles, including passenger cars and trucks. In fact, the devices were installed in all 2004 General Motors cars and several Ford models.

In its usual standardization role, the Institute of Electrical and Electronics Engineers (IEEE, **www.ieee.org**) recently published IEEE Standard 1616 for motor vehicle event and data recorders (MVEDRs), which is the term for equipment that collects, records, stores, and provides readout data about your vehicle's operation.

The information includes vehicle speed and changes in velocity, how many occupants are in the car, seat belt use or lack thereof, braking and steering data, geographic location, direction of travel, and other items, all linked to dates and times.

Proponents of MVEDRs argue that the digital data can complement accident information collected from victims and witnesses, improve vehicle design, reduce fraudulent insurance claims, and provide other useful benefits. However, many privacy advocates doubt the desirability of giving insurance companies and law enforcement agencies the ability to download a history of everything your car has experienced from the very moment you took it home and to use this information against you in unfortunate situations.

If you have any misgivings, it is now time to make them known to the auto companies and your elected officials. **NV**

The Business of Electronics Through Practical Design and Lessons Learned

In The Trenches

Analog to Digital Conversion Considerations

Using an Analog to Digital Converter (A/D) is really a fairly easy task for most non-critical applications. Unfortunately, there seems to be a lot of confusion about the steps that are necessary for a good conversion to take place.

This month, we'll examine the error sources and problems that occur when the necessary attention to detail is ignored.

The Sample and Hold

We'll limit this discussion to the common successive-approximation class of A/D converters. Perhaps because the manufacturers have made them so "easy" to use, hobbyists and engineers don't always stop to think about what actually happens when they press the "convert" switch. Without a doubt, carelessness is the major cause of improper A/D function.

There was a time when you had to buy a separate sample/hold (or track/hold) IC and attach it to your A/D.

Nowadays, everything is integrated into one chip and, in many cases — as with microcontrollers (µCs) — the A/D is only another feature. Just because you don't see the sample/hold doesn't mean that it isn't important or that it can be ignored. It is a critical piece of the conversion process. Understanding how it operates is important in understanding the limitations of the A/D.

Fundamentally, the sample/hold is just a means of stopping the input signal from changing during A/D conversion. The successive approximation procedure requires that the input signal be fixed; otherwise, the conversion can be corrupted. This is because there are N sequential comparisons for an N-bit converter. An eight-bit A/D needs eight comparison steps and a 16-bit A/D needs 16 steps, etc.

Obviously, these steps take time. If the input signal changes halfway through the sequence, the second half will represent the changed value. You can see that even a small input change can result in a really fouled-up binary number.

A practical example will show the importance of the sample/hold. Let's say that you have a 12-bit A/D — *without* a sample/hold — that takes 1 µS for each of the 12 steps for a conversion speed of 12 µS. What is the fastest sine wave it can

sample without error? Re-stating this in different terms: what is the fastest sine wave that doesn't change by one Least Significant Bit (LSB) in 12 µS (given a full-scale sine wave)?

One LSB is 1/4,096 or 0.000244 of full-scale. This is also 0.0140 degrees of a sine wave. So, the signal can't vary 0.0140 degrees in 12 µS. There are 25,714 of these 0.0140 steps in a full 360 degree sine wave. Each step requires 12 µS. So 25,714 steps at 12 µS each give a period of 0.3086 seconds or a 3.24 Hz frequency. That's right. Without a sample/hold, the 12-bit A/D is frequency limited to about 3.34 Hz, even though the conversion takes only 12 µS. Now, it is clear why the sample-hold is needed.

A sample-hold is simply a capacitor that can be disconnected from the input signal. When this is done, it maintains its charge — for a while, anyway. No capacitor is perfect. There is leakage through the capacitor insulation. This is called "droop." Obviously, you don't want the droop to be more than one LSB over the conversion interval. This means that you want a large value capacitor.

Unfortunately, a large value capacitor requires a large charging time, as well as large charging current, so there is a trade-off. Most manufacturers make the hold capacitor as small as possible for maximum speed. If the conversion speed is fast enough, a small capacitor will work well.

There is also the series resistance of the IC to the capacitor. No switch conductor is perfect. This means that there is a resistor-capacitor (RC) network made from the hold capacitor and the input resistance. This causes a delay or phase error. We'll discuss phase error in more detail later.

How big are the RC values? Let's look at the popular Microchip PIC µC. The basic eight-bit A/D is detailed in the section titled "A/D Sampling Requirements," as well as in Sections 21 and 22 of the 1997 PIC Micro Mid-Range MCU Family Reference Manual. Here, you find that the hold capacitor is about 51 pF and the series resistance (due to the electronic switch) is about 7,000 Ω.

It should be noted that this resistance varies considerably with supply voltage. They provide lots of detail on the A/D hardware. (Some other companies don't.) Since the Microchip people are very considerate, they have tables that specify the proper A/D clock rates for various system clock speeds. You don't have to actually figure them out for yourself. It is very important to follow their advice; otherwise, your A/D may lie to you.

Nyquist Nonsense

It is true that, if you sample more than twice the highest frequency of interest (Nyquist limit), you can recover the complete signal, but it is only true if you process those samples with a Fast Fourier Transform (FFT) or other sophisticated digital signal processing procedure. For virtually all applications using a small µC, this is not practical.

This means that Nyquist is not really useful to apply. The idea that you won't have any errors if you sample at the Nyquist limit is simply wrong. Trying to apply Nyquist-like concepts to a system without digital signal processing invariably causes problems. Let's look at some examples (in systems without digital signal processing).

Filtering

I've seen people work very hard to eliminate all higher frequency components from their signal before applying it to their A/D because they remember that aliasing can occur. Aliasing is caused when sample clock and signal frequency mix or "beat." This beat frequency cannot be distinguished from a real signal of that frequency after sampling. (There are special exceptions to this rule.) After all, this is what they were taught and this is what they're going to do! Unfortunately, blind faith is a poor virtue in engineering.

Here's an example: A robot had photo-interrupters on two wheels that were used to determine rotation rate and

wheel position. These signals peaked at 3 volts and were roughly rectangular in shape, so an A/D was used (rather than a digital method). We all know that square or rectangular wave shapes have loads of higher-order harmonics, so a filter was needed. Right?

Unfortunately, in this case, filtering simply made things very bad. The filters actually worked very well. The resultant wave looked very much like a sine wave. All the higher frequency components were removed, but what really happened was that the system was changed from measuring time relationships to voltage relationships. A little dirt on the sensor changed the voltage levels, which the software saw as a changed wheel position. Performance was poor. Removing the filter made things much better. Why?

It goes back to the sample-hold we talked about before. First, there was the RC network that acts like a low-pass filter, but — much more importantly — the sample-hold was disconnected from the signal during conversion. All those higher order harmonics were not present in the "held" sample.

Fundamentally, the analog signal was changed to a stepped-DC signal, which significantly reduced the high frequency components automatically. (This is not true for some special very high speed A/Ds.)

I don't think I've ever used an anti-aliasing filter on a µC product. I've filtered to reduce noise, to eliminate strong RF (which can really create problems), and to clean up signals. You will need a filter if you are going to recreate the input signal with digital signal processing or, perhaps, if you are sampling a signal close to the Nyquist limit. If you know what your input signal is and how your A/D works, you really should be able to anticipate most near-Nyquist problems.

Amplitude Errors

No A/D will ever provide you with the precise maximum or minimum value for a sine wave. It may be close. It may be so close that it doesn't matter, but it won't be exact. If you think about it, it becomes clear. The sample-hold capacitor is connected to the signal for a finite time. During that time, it effectively averages the signal. Therefore, the single peak value will be diluted with lower than peak values (and vise versa for the minimum value), but this isn't the major cause of amplitude errors. The biggest source of amplitude errors comes from the sampling rate.

Let's look at an example. You have a 1,000 Hz sine wave that you sample at 100,000 Hz. It seems like 100 samples per cycle should be adequate, right? If you use 100 conversions per sine wave, you will have one conversion every 3.6 degrees. So, you can have up to a 3.6 degree error in amplitude. At the zero crossing point, this corresponds to a 6.3% amplitude error. You may have thought that your eight-bit A/D converter would provide 0.4% error. In reality, you will have only 6.7% error (6.3% + 0.4%).

How many samples per cycle are needed for one LSB error? With eight bits, there are 256 amplitude levels, with the worst case/largest level being 0.224 degrees (inverse sine of 1/256). There are about 1,607 of these increments per 360 degrees (360/0.224). This means that you have to sample at 1,607 samples per cycle or 1.607 MHz for a maximum 0.4% amplitude error. Don't forget to add in the basic A/D error of 0.4% for a total error of 0.8%. Faster sampling will reduce the error, but you will always have a minimum A/D error of 0.4%.

Frequency/Period Errors

Generally, you don't directly measure the frequency of a signal with an A/D. Rather, you measure the period of a single cycle and invert it to get the frequency. Naturally, there are errors that show up here, as well.

Let's look at our 1,000 Hz signal, sampled at 100,000 Hz. As we noted above, each sample is 3.6 degrees and, therefore, the basic error can be 3.6 degrees. This means that, instead of 360 degrees per period, it could be 356.4 degrees. This is an error of 1% (obviously, because we are sampling

at 100 samples per cycle). If we measure from zero crossing to zero crossing point (the proper method), the basic A/D error is 0.224 degrees (see above). So, our total error can be a maximum of 3.82 degrees or 1.06%. The 1,000 Hz signal might be measured as 1,060 Hz. Again, this is well in excess of the basic 0.4% eight-bit A/D error.

You can improve things by sampling faster. You will need to sample every 1.44 degrees (0.4% of 360) or 250 samples per cycle to match the A/D error of 0.4%. For our 1,000 Hz signal, this comes to a 250,000 Hz sample rate.

Another way to increase the accuracy of your measurements is to measure multiple cycles. This is usually easy to do. Count 10 cycles instead of one for a 10-fold increase in accuracy. This spreads the error over 10 cycles and reduces the per-cycle error by 10. (Many hardware frequency counters do this. Some count 1,000s of cycles for very high accuracy.)

Phase Errors

The last basic error is phase. (Amplitude, frequency, and phase define any signal.) Basically, this is a delay error from the sampling and conversion process. This is probably the most obvious error of the three. Generally, it is usually the least significant. However, there are times when phase error can be really nasty.

First, how much error is there? With 100 samples per cycle, the error is 1% or 3.6 degrees. However, this is only due to the sampling error. There is also the acquisition error. This depends on how long the sampling process takes. Usually, this is much less than the sampling error, but it is important to verify that. (We will ignore that factor because it is A/D dependent.)

The worst case phase error from the A/D comes at the peak and trough of the sine wave where the amplitude changes take a relatively long time. This is the opposite of the frequency error above. The amplitude error can be 1/256 of full-scale. This corresponds to 0.996 instead of 1.000 (full-scale equals 1.000). The inverse sine of 0.996 is about 85 degrees. This is a difference of 5 degrees from the proper value of 90. Add this 5 degree error to the sampling error of 3.6 degrees and there is a whopping 8.6 degree potential phase error (or 9.5%) at 90 degrees. This is nearly 25 times worse than the basic A/D error of 0.4%.

How fast do we need to sample to get the phase error down to our basic 0.4% A/D amplitude error? Quite simply, you can't get there from here. We just saw that there was an inherent 5 degree error due to the step-size of our eight-bit A/D. An eight-bit A/D is just not good enough to resolve 1.44 degrees (0.4% of 360 degrees). We will need a step-size of 0.03%, which corresponds to about 3,000 steps — which means a 12-bit A/D converter.

Here's how those values were determined. Our desired resolution is 1.44 degrees. The worst case point is at 90 degrees. So, we have to be able to resolve the difference in amplitude between 90 degrees and 88.56 degrees (90-1.44). The sine of 90 degrees is 1.000 and the sine of 88.56 degrees is 0.99968. They differ by 0.00032. This defines the minimum step-size necessary (with a full-scale of 1.000). There are 3,125 steps of 0.00032 in a full-scale value of 1.000 (or 1/3125). A 12-bit A/D has 4,096 steps.

We still have to sample faster, too. We saw that 100 samples per cycle yielded a 3.6 degree error. It's easy to calculate our sampling speed for 1.44 degrees per sample. It's just 360/1.44 or 250 samples per cycle.

With our 1,000 Hz signal, our new sampling speed is 250,000 Hz (with a 12-bit A/D).

Think

The purpose of these exercises is to show how carelessness can create significant problems. It's important to stop and think about what actually happens during an A/D conversion. It's important to be able to determine these fundamental sources of error.

Also, of course, it's critical to understand how these errors can affect your design.

Most of the time, you should have a good idea of what signal you expect your A/D to see. You should always know what is to be done with the A/D data, even if that is not your job. It makes no sense to design eight-bit hardware when the software requires 12 bits of resolution. Many times, the A/D is only measuring a slowly varying signal, which is essentially DC (like room temperature).

In such cases, the error considerations are simple, but don't think all situations are like that. It can't be over-emphasized that you need to know which signal parameters are important (amplitude, frequency, phase) and how to determine the error budget for your application.

Error Is in the Eye of the Tester

You may have noticed that there are a number of ways to calculate the above errors.

For example, you might argue that the worst case frequency error should be measured from peak to peak rather than from zero crossing to zero crossing. The zero crossing procedure gives a smaller error. Conversely, the phase error could be reduced by measuring zero crossings rather than peaks.

"Standard engineering practice" dictates how these errors are measured. However, I am not aware of any reference that details what "standard engineering practice" actually is. There are books on "standard methods," but these are chemical analytical techniques. I'm also sure that there are probably references in various text books and manuals that provide occasional examples, but I haven't found anything like a collection of standard engineering practices. (If you know of such a collection, let me know.) These techniques are usually learned from experience.

First, all errors should be defined as worst case errors. "Average" errors or "typical" errors should never be used without first stating — very clearly — what the worst case error actually is. Proper engineering must always

account for the worst case scenario. Otherwise, failures will occur. Some failures are trivial. Others can be catastrophic. No good engineer tolerates a failure based on faulty error estimates or wishful thinking.

So, why is the above frequency error not the absolutely worst error possible? It's because the accepted practice is to measure the frequency of a signal with the zero crossing points. There are two basic reasons for this. The first is that it's pretty easy to determine the zero crossing points. The second is that the steepest slope of the sine wave is there, which makes the measurement the most precise. The error calculated above is the worst case using standard engineering practice.

The phase error is not measured that way because proper phasing implies that there are two systems working together. (Any phase measurement must relate to another phase measurement.)

Typically, phase measurements are used in motors or positioning systems. In such applications, phase comparisons are required over the whole 360 degree range. Therefore, the worst case error must be defined for a full 360 degrees. This is very different from the frequency measurement that only required two points on that 360 degree interval.

Reducing the Errors

There are two common ways to reduce basic errors at the A/D. As noted above, you can increase the sampling speed or increase the resolution. You can also use software. Probably the easiest method is to use multiple measures. I've discussed this previously in my "Statistics" columns (May and June 2004). Very briefly, you can increase the precision of a system by taking repeated measurements of the same signal and averaging them. The noise in the measurements will tend to cancel, while the true signal will tend to reinforce itself.

In theory, you can generally expect a decrease in error that is equal to the square root of the number of measures. (Four measures reduces the error by a factor of two; 100 measures reduces it by a factor of 10.) There are other, more complicated methods, as well. No error reduction system is suitable for every application. Be sure the method you choose is appropriate.

Conclusion

Using a basic low speed A/D is not always as simple as it first appears. Amplitude, frequency, and phase errors may be much larger than expected. Knowing how to anticipate and calculate these errors is an important part of data acquisition. **NV**

Tech Forum

QUESTIONS

I have an RV and I installed a homemade electronic rear-view mirror. I already had a 5" monitor and connected it to a $39.00 CMOS black-and-white camera with 0.1 lux light sensitivity. It works fine, but the image is opposite from a mirror view when viewed on the monitor. I solved the problem by pointing the camera vertically into a mirror positioned at 45 degrees to the rear.

There are cameras with mirror switching capabilities, but I've been unable to locate one with 0.1 lux or better sensitivity. I would like to know about modifying an existing unit or if reversing the function is built into an LSI chip where I can't get to it? A functional diagram or schematic of a camera would be helpful.

#1051 **Anonymous via Internet**

I am looking for a simple on/off switch that can be triggered by electrodes placed on the skin. It needs to have a sensitivity adjustment. I would also like to have it opto-isolated for safety. Any suggestions or places I can look?

#1052 **Chris Tauscher via Internet**

I have acquired an HP 7580b plotter that is mechanically sound. When I turn it on, E02 is displayed after a self-test. The operator manual says it's a microprocessor error/ROM checksum error. When I plot a drawing, it plots to one side and only half of the drawing is on the page. HP does not support this plotter any more and I am having trouble acquiring information on how to troubleshoot. Where should I start?

#1053 **Alex Malachowski via Internet**

Anyone know of an after-market lens to convert a common PC board camera into a microscope with a magnification between 60 and 150X?

#1054 **Joe R. via Internet**

I recently purchased a communications test set for aligning my ham radio related equipment. The output generator's frequency is set using thumbwheel switches. Although I have had no trouble aligning receivers with this piece of test equipment, I got quite a surprise when I attached three frequency counters to the output. The readings go wild, but — when I connect them to older signal generators — the responses are as expected. After hooking the test set to my oscilloscope, I saw the reason. The signal generator is synthesized, not a pure sign wave, and is chock full of harmonics.

How, if at all, can I filter the output sufficiently so a frequency counter can be properly used? A series of low pass filters lined up to be switched in and out up to 1 GHz seems a little far fetched.

#1055 **John Ciperano K4EBC via Internet**

I'd like to use X10 cameras and receivers — such as those sold by **www.x10.com** — to beef up the security of my home, inside and out.

The problem is that the units do not secure their transmissions, which leaves me vulnerable to outsiders seeing inside my home, knowing where things are, and whether or not someone is at home. I've contacted the resellers and they confirmed they have no security.

This is a READER-TO-READER Column. All questions AND answers will be provided by *Nuts & Volts* readers and are intended to promote the exchange of ideas and provide assistance for solving problems of a technical nature. All questions submitted are subject to editing and will be published on a space available basis if deemed suitable to the publisher. All answers are submitted by readers and NO GUARANTEES WHATSOEVER are made by the publisher. The implementation of any answer printed in this column may require varying degrees of technical experience and should only be attempted by qualified individuals. Always use common sense and good judgement!

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ANSWER INFO

• Include the question number that appears directly below the question you are responding to.

• Payment of $25.00 will be sent if your answer is printed. Be sure to include your mailing address if responding by email or we can not send payment.

• Your name, city, and state, will be printed in the magazine, unless you notify us otherwise. If you want your email address printed also, indicate to that effect.

• Comments regarding answers printed in this column may be printed in the Reader Feedback section if space allows.

QUESTION INFO

To be considered

All questions should relate to one or more of the following:

1) Circuit Design
2) Electronic Theory
3) Problem Solving
4) Other Similar Topics

Information/Restrictions

• No questions will be accepted that offer equipment for sale or equipment wanted to buy.

• Selected questions will be printed one time on a space available basis.

• Questions may be subject to editing.

Helpful Hints

• Be brief but include all pertinent information. If no one knows what you're asking, you won't get any response (and we probably won't print it either).

• Write legibly (or type). If we can't read it, we'll throw it away.

• Include your Name, Address, Phone Number, and Email. Only your name, city, and state will be published with the question, but we may need to contact you.

Can anyone suggest a means to securely transmit data from the X10 cameras to the receivers? External methods are okay, but I suspect tapping inside connections would work best.

#1056 **Errol White**
via Internet

Regarding reading an ADC output from an aperture opening, then advancing film or paper to be cut, I understand the ADC and the electronics. I know little about programming; could this be done with a PIC?

#1057 **Arthur Williams**
Ashland City, TN

I'm using an LM3909 in a circuit to control a flashing red and green light on a model railroad. Is there a pin-for-pin replacement for it? If not, is there one that isn't pin-for-pin?

#1058 **R. Thompson**
Richmond, MO

ANSWERS

[20410 - February 2004]

I have a surplus VFD display module, but no specs. It looks like one of those large cash register displays that's mounted on a pole. Inside is a pair of Futaba M202LD01DA vacuum fluorescent displays. The interface cable has eight pins where 20 VDC power is applied and an RS-485 serial interface is used to talk to the modules.

I, too, have one of these displays. I talked to the engineers at Futaba, who said that this display unit is a customer-proprietary product and no information is available.

They did allude to the fact that the ROM uses a completely unorthodox pattern for addressing the display. I've searched the Internet without success and even pulled a few strings at Futaba with the same results. Sorry.

Ed Edmondson, Jr., Ph.D.
Alamosa, CO

[3046 - March 2004]

Does anyone have a simple circuit that uses an IR sensor to trigger a camera? I'd like to snap pictures of the nocturnal visitors in the backyard of my country home.

#1 A simple solution — though perhaps expensive — is to buy a Stealth Cam. Sportsman's Guide (**www.Sportsmansguide.com** or 800-882-2962) has two models on their website These units are self-contained, weatherproof 35 mm cameras. They use standard 35 mm film slides — print or black-and-white. They sense motion and take pictures with flash. They have options for how many pictures at a time and how long to delay between pictures. The cheapest is part number WX2-73967 at $79.97.

Jim Schmidt
Deer Lodge, MT

#2 Buy an IR floodlight (motion-sensing flood light) unit at Home Depot. Remove the floodlight lamp sockets and wire a relay with a 120 VAC coil in place of one of the sockets. Control the camera with the relay contacts. The cost is about $10.00 for the sensor and $5.00 for the relay.

Anonymous
via Internet

[50410 - May 2004]

I have an old keyboard (from a Wyse 2108 computer, vintage 1988 or so). It has a fantastic touch that I have been unable to find in modern keyboards. I've tried all 24 possible combinations of the four signals in an adapter cable, but none of them works. I'm guessing that there is some other incompatibility preventing this old keyboard from working on a more modern computer.

The Wyse 2108 is not a computer, but a terminal. What you can do is use it at such by installing Linux on your PC and connecting the Wyse to a serial port that is configured as a terminal line. Unfortunately, you can only use shell commands on your terminal and not all the fancy graphics environments and applications that are available for Linux nowadays.

Therefore, a better solution for your question is to get an old PS/2 or USB keyboard for free somewhere in the garbage or at a flea market. Each keyboard has a controller that converts keys connected in a matrix to the PS/2, USB, or other bus protocol. (The first IBM-PC keyboards back in the 1980s were equipped with the 8048 microcontroller.) Your task now is to connect the Wyse terminal keys to the matrix of the controller which was obtained from the "garbage" keyboard.

Gerrit Polder
The Netherlands

[9042- September 2004]

I am trying to find info on a kit that was offered back in Radio Electronics Magazine *called the HyperClock. It was offered by an outfit named SkiTronix around 1991. I built one back in high school and it has just now failed. I cannot locate the schematics or magazine issue that featured it. Searching the web has not yielded anything.*

This was answered by many *N&V* readers, but William Richter was the first to supply a photocopy of the actual article to Rich White. Thanks, William! — Editor Dan

[10046- October 2004]

I just installed new AT & T 2.4 GHz phones: a base and three handsets. Now — if all the phones are in their charging cradles — I get big, double horizontal bars on TV channels 4 and 5 and buzz on my portable FM radio. If the phones are out of their cradles, everything is okay.

They are no doubt using pulse width modulation to regulate battery charging and the shielding is poor.

Try purchasing a choke core (RadioShack 273-104) and wind the power cord through it per the directions. Put the choke as close to the base unit as possible. If that is not sufficient, try wrapping the base units in aluminum foil. If that works, I would return them and demand my money back.

Russ Kincaid
Milford, NH

[10047- October 2004]

I've just picked up a couple of 6" neon light tubes that I want to put into my PC. The tubes were sold for automotive use and have power converters — 12 VDC/150 mA in, 1,000 V/15 mA out. I could buy a module that will "blink" the lights to music, but I want a different effect.

I want the lights to appear to "breathe" — slowly dimming to some adjustable level (maybe 30-40%) and then going back to full brightness again without pause.

In short, you cannot slowly dim a neon tube. You can flash the tube on/off, but not partially dim it. Any neon gas discharge tube has a distinct voltage value where it will begin conducting current. Any voltage below the turn-on point will do nothing to the tube because the tube has a very high resistance between its terminals (so no current can flow and no glow is emitted). Once the turn-on voltage is reached, the resistance across the terminals drops very low and the neon gas conducts current emitting the glow you see.

The voltage — say 1,000 volts — must be current limited to only a few tens of milliamps, typically. This can be done with a series resistor or electronically in the design of the power supply. An increase in the specified operating voltage or current may make the tube slightly brighter, but at a great reduction to its life. Lowering the voltage will make almost no change in brilliance and then, suddenly — when the cut-off voltage is reached — the tube will stop conducting.

Input is given at 12 volts DC. You cannot decrease this voltage, as the power supply will not work properly and increasing significantly above 12 volts may result in damage to the tube or power supply.

Erik von Seggern
via Internet

[11041- November 2004]

Does anyone know of a source or replacement for a 95H0359 180 MHz triple or/nor gate IC? It was used in a Heathkit IB-1103 frequency counter, part number 443-79.

I would consider buying a complete unit (eBay) as spare parts.

I see IB-1103s selling in the \$10.00-\$20.00 range. This way, you will have a complete set of replacement parts — including the nixie tubes — should other parts fail.

If you know the internal logic of the device (sometimes this will be shown on the schematic), it may be possible to replace the device with a programmable logic device. Just make sure that the supply voltage is correct because some of Heathkit's digital logic ran in the 3 V range, not 5 V. Have a look at the PALCE16V8 (AMD), GAL16V8 (Lattice), and XC7500 (Xilinx) series of devices.

I'd try Motorola and National Semiconductor Databooks. The part may have been given an OEM part number for sale to Heathkit, but most likely it was also sold as a standard device under a more well-known part number. If it is a 5 V device, try looking in the 7400/74LS/74ALS/74F series for a device with the same functionality and pinout.

Phillip Stevens
Pocasset, MA

[11044- November 2004]

I need a variable speed PWM controller that can drive a brushed DC motor at 48 volts (or higher) and at about 200 or 300 amps. Is there, perhaps, a kit? It's for an electric bike.

While I do not know of any kits with those ratings, you should check with your local forklift dealer about a "General Electric 'EV-1'" controller. They are used in a lot of forklifts and have the ratings that you require. They seem to work forever without much — if any — maintenance.

Ron Baxter
Hayward, CA

[11047- November 2004]

I am trying to find articles on building a DC accumulating ammeter, similar to an AC watt/hour meter. It will be used to monitor the charge/discharge of an "off the grid" home power source.

The exact solution to this question was published in the November 1994 issue of *Popular Electronics Magazine* as a construction article starting on page 50. It is an easily constructed battery ampere-hour meter that is powered by a 9 V battery. It works in both directions and will accumulate the number of Ah delivered to a load or to a battery under charge.

The load current is passed through a 0.1 Ω resistor connected to a linear current-to-voltage converter that provides 1 V per ampere output. A Teledyne voltage-to-frequency converter chip — TC9402CPD — is used to convert the detected voltage to a frequency. The output frequency of the Teledyne chip is adjusted to 582.5 Hz when the detected current is 0.1 ampere.

A CD4045 binary divider chip is used to divide the 582.5 Hz down to a frequency of 0.000278 Hz, which is 1 pulse per hour for each 0.1 ampere of current. This is followed by a set of two CD4029 counter chips driving a pair of LCD display modules, which provide a two-digit display of the ampere-hour count in increments of 0.1 Ah.

Anthony J Caristi
Waldwick NJ

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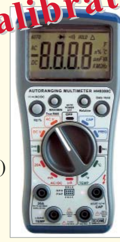

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